Breadth of external knowledge search in service sectors

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Abstract

Purpose – There is a dearth of empirical research on the impact of external knowledge search on innovation performance in different categories of service firms. This study explores the effectiveness of the breadth of external search on product and process innovations in German firms. In particular, we model a non-linear relationship between the breadth of knowledge and product and process innovations.

Design/Methodology/Approach - Drawing on the Mannheim Innovation Panel (MIP) data for the German service firms in the period 2014-2016, we report findings from a bivariate probit model, which takes into account mutual interdependence between product and process innovations. Moreover, the model is separately estimated for knowledge-intensive business services (KIBS) and other services. For comparative purposes, we also estimate the model for manufacturing firms.

Findings - Empirical findings uniformly show an inverted U-shaped effect of the breadth of knowledge on both product and process innovations. Furthermore, the results demonstrate that using up to three knowledge sources increases the probability of a joint implementation of product and process innovations. These findings hold for all subsamples- KIBS firms, other services. However, those service firms that focus on a single type of innovation experience diminishing returns to external knowledge when exploiting more than one source of knowledge. These results suggest that a simultaneous introduction of different types of innovation requires diverse knowledge sources. In contrast, when focusing on a single type of innovation, service firms experience diminishing returns when using multiple sources. However, this finding is only partially found for manufacturing firms. Accordingly, our findings provide support for the demarcation approach, insofar as the breadth of knowledge has a heterogenous impact on innovation in manufacturing relative to service firms.

Originality/value- Previous studies on the breadth of knowledge search mostly examined its influence on innovation performance without separately analysing manufacturing and service firms. The present study focuses on service firms, that are further divided into KIBS and other service firms. By investigating potentially non-linear relationships between knowledge breadth and product and process innovations, it illustrates how different innovation strategies are affected by a diverse pool of external knowledge sources.

Key words: Knowledge search; Knowledge breadth; Inbound open innovation; Knowledge-intensive business services; Product and process innovations

1. Introduction

This study explores the impact of the breadth of external knowledge search in the German service sector. Search breadth refers to the use of diverse external knowledge sources or information from external parties (Gómez *et al*., 2016; Greco *et al.,* 2015; Mention, 2011; Radicic and Pugh, 2017; Terjesen and Patel 2017). The topic has been investigated from the knowledge-based perspective as well as within the open innovation approach. The focal point of the knowledge-based view of the firm (Grant, 1996) is that firms need to integrate external knowledge into their knowledge base (Criscuolo *et al*. 2018). The concept of open innovation, first introduced by Chesbrough in 2003, reinforces the importance of knowledge flows among economic agents in the innovation ecosystem (customers, suppliers, competitors, universities, research organizations etc.) (Criscuolo *et al*. 2018; Mention 2011).

Although more than 70% of value added in the Euro Area can be attributed to the service sector (Cainelli *et al*., 2020), the literature on innovation activities in service firms is still scarce (Rodriguez *et al*., 2017; Un and Montoro-Sanchez, 2010), in particular in terms of the degree of openness and its impact on firms' innovation performance (Battisti *et al*., 2015; Mina *et al*., 2014; Rodriguez *et al*., 2017). Although all types of open innovation practices (inbound, outbound, and coupled) play a significant role in enhancing firms' innovation performance, this study focuses on inbound practices, in particular, the use of external knowledge sources. Their importance in the context of service firms is particularly pronounced given that R&D activities might be less relevant for service firms relative to manufacturing sectors (Cainelli *et al*., 2020; Mina *et al*., 2014). However, on the other side, higher absorptive capacity (Cohen and Levinthal, 1990), usually proxied by internal R&D investment (Denicolai *et al*., 2016; Laursen and Salter, 2006), is a necessary condition for the extensive use of external knowledge (Battisti *et al*., 2015; Lopes and Carvalho, 2018; Wu, 2014). This is consistent with the resource-based view of the firm, which suggests that firms seek complementary resources when selecting external knowledge sources (Gómez *et al*., 2016; Mention, 2011; Reichstein and Salter, 2006; Rodriguez *et al*., 2017).

Firms can choose between cooperation, which is a formal, contractual arrangement for knowledge exchange, or they can exploit information sources from external partners. The latter is regarded as a weaker or indirect form of cooperation, in which the focal firm benefits from knowledge spillovers (Mention, 2011). Informal use of external information relies on partners' mutual trust and moral obligations rather than on formal arrangements. Given that the most prominent features of services are their intangible nature and that innovation is often introduced ad hoc, informal knowledge exchange is usually favoured relative to legally binding contracts (Leiponen, 2012; Mina *et al*., 2014). Following this argument, we focus on this type of knowledge exchange.

The present analysis addresses the effectiveness of knowledge breadth in the context of product and process innovations in service sectors (and manufacturing, for the comparative purposes). In doing so, this study makes three contributions. First, we model a potentially non-linear relationship between the breadth of external knowledge and product and process innovations. Namely, previous empirical studies on external search have suggested that firms might over-search, i.e. the effectiveness of external knowledge decreases after a certain number of sources are explored (Battisti *et al*., 2015; Laursen and Salter, 2006; Radicic and Pugh, 2017; Radicic *et al*., 2019). Our study tests this hypothesis in the service sector. Second, the impact of open innovation on process innovation is less investigated (Gómez *et al*., 2016), in particular concerning the search for external knowledge (Terjesen and Patel, 2017) and its potential non-linear impact on process innovation (Greco *et al*., 2015). Exploring external knowledge sources help firms to discover new ways of solving problems and introducing novel combinations and products. Product innovation is not the only type of innovation that can benefit from firms' search across diverse knowledge sources. Firms can also discover new technologies or new applications of existing technologies, and thus introduce process innovations (Wu, 2014). Consequently, this study focuses on both product and process innovations and explores whether service firms experience diminishing returns to external knowledge search. Third, we investigate whether a non-linear impact of knowledge breadth varies with a firm's innovation strategy. Namely, we distinguish between three strategies: complex innovation (i.e. a simultaneous introduction of product and process innovations), only product innovation and only process innovation (Le Bas and Poussing, 2014). Our empirical findings demonstrate that the optimal level of knowledge sourcing varies between complex and single innovators. Finally, we separately analyse firms operating in knowledge intensive business services (KIBS) and those operating in other services. The service sector is known for a variety between and within individual service sectors (Castro *et al*., 2011; Mina *et al*., 2014). Thus, we explore whether the impact of the breadth of external knowledge is heterogenous between service sectors that are knowledge intensive compared to their counterparts, other services.

In this study, we use the latest wave of the Manheim Innovation Panel (MIP), which is the German version of the Community Innovation Survey, covering the period 2014-2016. We employ a bivariate probit model, which takes into account the interdependence between product and process innovations (Ayllón and Radicic, 2019; Gómez *et al.*, 2016; Reichstein and Salter, 2006). Our empirical strategy not only enables modelling the correlation between product and process innovations, but also estimating marginal effects for separate cases of complex and single innovation strategies.

The remainder of the study is organized as follows. In the next section, we review the literature on knowledge sourcing and the underlying arguments from the knowledge-based view and the concept of open innovation in the service sector. Then we present the data, empirical strategy and model specification. After discussing empirical findings, we conclude with theoretical and managerial implications.

2. Literature review and hypothesis development

Firms can choose to cooperate for innovation by engaging in formal knowledge exchange or to use external knowledge sources without entering legally binding contracts. Regardless of which option firms choose, theoretical arguments for the use of external knowledge stem from the resource-based view (Barney, 1991) and its extension, the knowledge-based view (Grant, 1996), as well as the open innovation (OI) concept (Chesbrough, 2003). The resource-based view of the firm argues that firms use external knowledge to utilise and expand their internal knowledge base, i.e. absorptive capacity. Namely, by accessing both complementary and similar knowledge from other firms and organisations, firms can expend their absorptive capacity and, in that way, obtain a competitive advantage over other firms (Arranz and Arroyabe, 2008). This argument is consistent with another important framework in the innovation literature, that of innovation ecosystem, in which cooperation for innovation, besides integrated value chains, is its core attribute (Xu *et al.*, 2018). Within a wider innovation ecosystem, technological diversity among firms and other economic agents is the basic motivation for cooperation for innovation. Greater technological diversity increases the probability of firms' collaborating on complex products that are harder to imitate, and as such, become a source of firms' competitive advantage (Radicic *et al.*, 2018).

Looking at individual types of partners, vertical cooperation usually entails gaining access to complementary resources. While cooperation with suppliers is usually focused on cost reduction from process innovation (Belderbos *et al.*, 2004), customers are particularly relevant source of information and knowledge when firms commercialise new products (Arranz and Arroyabe, 2008; Belderbos *et al.*, 2004). Regarding vertical cooperation, firms cooperate with competitors to access similar resources (Radicic *et al.*, 2019), but the issue of appropriability of technological knowledge is particularly relevant for this type of cooperation. Finally, firms cooperate with private and public knowledge providers (e.g. universities, private and public research institutions, consultants), to access complementary knowledge, often associated with basic research. On the other hand, cooperation with universities, because of its orientation towards basic knowledge, might be riskier, more complex and take more time than inter-firm cooperation, which focus tends to be on applied research and commercialisation (Belderbos *et al.*, 2004).

The importance of external knowledge in firms' innovation activities is further emphasized within the concept of open innovation. Chesbrough introduced the concept of open innovation in 2003. He defines open innovation in the following way: "open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" (Chesbrough 2006, p. 1). High market dynamics combined with short product life cycles and increasing cooperation between companies and other economic agents in the innovation ecosystem creates a base of a new model in innovation management (Gassmann and Enkel, 2004; Chesbrough and Crowther, 2006; Vanhaverbeke *et al.*, 2008; Schroll and Mild, 2011). Even though the evidence of open innovation approach to innovation management was first identified in high technology industries, this approach is widely used in all types of companies, including low and medium technology industries and services (Chesbrough and Crowther, 2006; Batterink, 2009; Schroll and Mild, 2011). Companies in traditional or service industries also tend to open their innovation processes to external providers of knowledge, ideas and opportunities with the aim of improving their products and services, providing new values and enhancing their performance (Ebersberger *et al.*, 2012).

Gassmann and Enkel (2004) identified three main processes (types) of open innovation: outside-in (or inbound), inside-out (or outbound) and coupled process. The literature on OI identifies different types of inbound practices: a) technology scouting or knowledge sourcing[1] (Gassmann and Enkel, 2004; Love *et al.*, 2011; Mention 2011), b) customer involvement; c) outsourcing R&D and d) inward intellectual property licensing (Parida *et al.*, 2012). Opposite

[1] Informal networking, external search, search strategies, external knowledge flows, and external knowledge sources are used interchangeably in the open innovation literature (Radicic and Pugh, 2017).

to inbound OI, outbound OI is an inside-out process and includes venturing and outward licensing of intellectual property (Dahlander and Gann 2010). Finally, companies that practice coupled OI simultaneously use inbound and outbound practices, to obtain knowledge and to deliver ideas to market, and in that way, develop and commercialise innovation (Enkel *et al*., 2009). Coupled OIs encompass formal cooperative networking, such as joint ventures, cooperation for innovation and strategic alliances (Mazzola *et al*., 2012; Radicic and Pugh, 2017). Therefore, the choice between formal and informal use of external knowledge is reflected in the literature on open innovation, in which technology scouting (i.e. search for external knowledge) is termed inbound open innovation, while formal cooperation with various partners is termed coupled open innovation (Mazzola *et al*., 2012; Radicic and Pugh, 2017).

By tapping into multiple knowledge sources, firms increase the probability of discovering novel combinations. That is, the more sources a firm is using, the more likely is that at least some of them will contain information that are useful for the firm's innovation activities (Ardito and Petruzzelli, 2017; Leiponen, 2012). To be able to search, absorb and exploit external knowledge, firms needs to develop absorptive capacity. In turn, when external knowledge is absorbed, it expends firms' knowledge base and thus absorptive capacity (Denicolai *et al*., 2016; Terjesen and Patel, 2017; Vega-Jurado *et al*., 2009). In other words, there is a reverse causality between absorptive capacity and external knowledge sourcing. Firms should use external knowledge as long as marginal costs are equal to marginal benefits. This theoretically optimal point needs to be estimated empirically, and that is why there is a stream of research investigating the effectiveness of knowledge sourcing on firms' innovation performance (Leiponen, 2012).

However, using multiple knowledge sources (i.e. search breadth) might have positive innovation effects up to a certain point, after which the returns become negative due to over-search (Laursen and Salter, 2006). Following Koput (1997), there are three potential causes of over-search. First, firms might benefit from multiple knowledge sources until their absorptive capacity is exhausted (Ardito and Petruzzelli 2017; Chen *et al*., 2011; Radicic and Pugh, 2017, Radicic *et al*., 2019). After this point, firms would experience decreasing returns to external knowledge. Second is the timing problem, which refers to situations when innovative ideas might not be fully exploited because they come at the wrong time (Ardito and Petruzzelli 2017). Third, "the attention allocation problem" might occur (Ocasio, 1997), when managers and creative employees have limited time and cognitive capacity to dedicate to many innovative ideas (Ardito and Petruzzelli 2017; Chen *et al*., 2011; Laursen and Salter, 2006). In other words, after exploiting a certain number of knowledge sources, managers would struggle to dedicate time and effort to additional sources. Based on these theoretical considerations, we formulate the following hypothesis:

> *H1: There is a non-linear relationship between the breadth of external knowledge and product and process innovations in service firms.*

Amara and Laudry (2005) propose that radical innovation requires a diverse use of external knowledge sources. We extend this argument and suggest that not only radical innovation, but also complex innovation, such as a joint introduction of different types of innovation (in the context of this study, product and process innovations, similar to Le Bas and Poussing, 2014) will benefit more from a wider range of information and knowledge sources, than single innovation, involving only product innovation or only process innovation (Le Bas and Poussing, 2014). If the problem of over-search pertains, it will arise at a higher turning point in case of complex innovators relative to single innovators. Therefore, we posit the following hypothesis:

> *H2: Decreasing returns to external knowledge occur at a lower turning point when firms engage in single innovations (i.e. only product or process innovation) than when firms are complex innovators (simultaneously introducing both types of innovations).*

Unlike goods produced in manufacturing firms, services are inherently intangible in their nature, have high information content and their production and the use are usually inseparable (Asikainen, 2015; Cainelli et al., 2020; Love et al., 2011). Furthermore, service firms innovate differently than manufacturing firms in many aspects. Innovation in service sectors often requires a simultaneous introduction of product and process innovation (Love et al., 2011; Mina et al., 2014). Moreover, service innovations are mostly incremental in nature, focusing on changes in existing products or processes (Asikainen, 2015). Another distinct feature of innovation in services is a weak role of permanent R&D investments, whereas R&D activities are often critical for producing innovation outputs in manufacturing firms. To compensate for lower levels of R&D activities, services firms are more likely to cooperate with external partners (Leiponen, 2012; Mina et al., 2014). Finally, it is more difficult to protect intellectual property in the service sector compared to manufacturing. Even though the literature stresses the differences between services and manufacturing firms in their innovation activities, they also share many similarities. Firms in both sectors need internal, human and financial, resources to be innovative. In addition, firms interacted with the environment through the open innovation practices, in particular through outbound and inbound knowledge flows.

Depending on whether similarities or differences prevail or if both are equally important, the literature has developed three perspectives. The first is the assimilation approach that assumes no substantial differences in innovation activities between service and manufacturing sectors, which means that innovation in services is assimilated within the consolidated framework used for manufacturing sectors (Wong and He, 2005). This approach focuses on product and process innovations (termed technological innovations in the *Oslo Manual*, OECD, 2018), while the relevance of organizational and marketing innovations (termed non-technological innovations in the *Oslo Manual*) is overlooked (Doloreux and Shearmur, 2012). The second is the demarcation perspective that emphasizes the peculiar features of innovation in services which require the development of concepts and models specifically designed for services (Cainelli et al., 2020; Wong and He, 2005). However, this perspective is seldom adopted in empirical studies, predominantly due to the lack of data (Wong and He, 2005) (e.g. the Community Innovation Survey does not include any specific questions that could be uniquely associated with innovation activities in services). The third is the synthesis perspective which recognizes that innovations in services and manufacturing firms have similarities as well as differences and attempts to develop a common conceptual framework that would be broad enough to encompass innovation in both sectors. A large number of empirical studies produced mixed evidence: some studies found no difference between services and manufacturing sectors, thus providing support for the assimilation approach, while others point out the differences between innovation modes in services versus manufacturing sectors, thus propagating the demarcation approach (for a review see e.g. Cainelli *et al*., 2020). Because of the lack of consensus in the literature, we not only report results for KIBS and other services, but also for manufacturing firms.

Main characteristics of services provided by KIBS are the critical role of knowledge (embedded in human capital and organizational routines) and the prevalence of high-skilled labour and advanced technology (Asikainen, 2015; Doloreux and Shearmur, 2012; Lafuente et al. 2019). Given that knowledge is the main driver of KIBS performance, their role in the knowledge economy is gaining prominence. The role of KIBS in economic growth is threefold: as an innovation enabler for other sectors; as a source of innovation and as a contributor to economic growth through its economic performance (Asikainen, 2015; Kekezi and Klaesson, 2019). KIBS firms provide knowledge intensive services to other, private and public, enterprises. By creating innovative solutions as well as facilitating the transfer of innovation from one firm to another, KIBS firms create significant knowledge spillovers across sectors (Doloreux and Shearmur, 2012). Although the role of customers has been recognized and extensively explored in the literature on KIBS, more recent studies have shown that other firms and institutions (such as suppliers, competitors, universities, research centres, etc.) positively affect KIBS innovation performance and competitiveness (Grandinetti, 2018; Li *et al*., 2019). In this context, we explore whether the breadth of knowledge sources has a differentiated impact in KIBS firms compared to less knowledge intensive service firms.

KIBS firms offer expert services to other firms, either professional (e.g. consultancy services) or technical (e.g. R&D development, information technology) (Kekezi and Klaesson, 2019; Lafuente et al., 2019; Miles et al., 1995). However, there is no universally accepted classification of KIBS (Kekezi and Klaesson, 2019; Mas-Verdú et al. 2011), although Miles et al. (1995) note that all KIBS need to satisfy three conditions: i) they employee highly educated workers; ii) they provide knowledge intensive inputs to other businesses; and iii) KIBS' customers are other firms. For instance, Strambach (2008) classifies KIBS into economic services, marketing/advertising, technical/IT, and R&D services. Therefore, KIBS include a variety of types of services, from marketing to legal services through consultancy, engineering, and technical analysis (Mas-Verdú et al., 2011). In our dataset, the industry categorisation is based on NACE Rev.2 and the industries are divided into 21 categories.[2] The KIBS category in our analysis includes media services (NACE codes 18, 58, 59 and 60), IT and telecommunications (NACE codes 61, 62 and 63), banking and insurance (NACE codes 64, 65, and 66), technical and R&D services (NACE codes 71 and 72), and consulting and advertising (NACE codes 69, 70.2 and 73).

2.1. Previous empirical evidence

Concerning empirical evidence on the impact of knowledge search on innovation performance of service firms, Mention (2011) investigates how three types of knowledge sources (market, research and informational) affect radical product innovation in services firms in Luxembourg. The only information sources found to increase the likelihood of radical innovation are from customers and suppliers. Few studies continued this line of enquiry (dividing sources into market, research and informational) by focusing on KIBS firms. Amara *et al*. (2009) explore how these three categories of sources affect product and process innovations (among four other types of innovation) in Canadian KIBS. The results from a multivariate probit model suggest

[2] Mining, retail, energy, water, transport equipment and postal services are excluded from the analysis, see Table A1 in Appendix.

that these sources have no impact on product and process innovations. Rodriguez *et al*. (2017) examined KIBS firms in Spain. Again, the results demonstrate a limited effectiveness of external sources for both radical and incremental product innovations. Namely, only market sources increase the likelihood of product innovation. Criscuolo *et al*. (2018) examine individual combinations of different external sources in the sample of the UK manufacturing and service firms. They conclude that product innovation is associated with broader searches than process innovation. Similarly, Ardito *et al*. (2017) and Greco *et al*. (2016) report a curvilinear relationship between the breadth of external search and product innovation, but these studies did not separate manufacturing from service sectors.

Concerning the manufacturing sector, a seminal paper by Laursen and Salter (2006) introduced a concept of the breath of search strategy and investigated its association with innovation performance in the UK manufacturing firms. Empirical findings reveal a curvilinear relationship, but it is worth noting that the study distinguishes between radical and incremental product innovations, which is not the case in our study. Similarly, Terjesen and Patel (2017) also analyse the impact of search breadth in the UK manufacturing firms, but on process innovation. Their findings are opposite to those of Larsen and Salter (2006), such that search breadth does not have a non-linear relationship with process innovation. Moreover, its impact is negative, i.e. as a firm uses an increasing number of external sources, the probability of process innovation diminishes.

There are few studies that look at the influence of the knowledge breadth in the service sector. Cainelli *et al*. (2020) examine the determinants of product innovation in Spanish KIBS and high-tech manufacturing firms. They report that the breadth and depth of external knowledge search is more important for KIBS firms than for high-tech manufacturing firms. Leiponen (2012) compares the effects of the breadth of knowledge in Finish service and manufacturing firms. Empirical findings demonstrate that both service and manufacturing firms benefit from a diversity of information flows arising from multiple knowledge sources. However, she did not include a square term in the model, which means that a potentially curvilinear impact has not been tested.

As can be seen from the empirical literature review, previous studies are characterized with a heterogeneity in the types of innovation examined and how external knowledge search is measured. Furthermore, there are very few studies exploring the effectiveness of external knowledge sourcing (closest to our study is Cainelli *et al*., 2020), while no studies examined a potentially non-linear effect of external knowledge on product and process innovations in service firms. Likewise, no study reports these effects for complex and single innovators.

3. Methodology

3.1. Data

The Mannheim Innovation Panel (MIP) dataset used in this study has been collected by the Centre of European Economic Research together with the Fraunhofer-Institute for System and Innovation Research and the Institute for Applied Social Sciences on behalf of the German Federal Ministry for Education and Research (BMBF). The MIP is an annual innovation survey based on a panel sample of German firms that constitutes the German contribution to the European Commission's Community Innovation Survey. Our study focuses on the latest wave conducted in 2017 and covering the period 2014 -2016. The full sample consists of 5,189 firms in both manufacturing and service sectors. After removing missing values, our effective sample is 2,501 firms, out of which 651 firms operate in knowledge intensive business sectors (KIBS), 545 firms operate in other service sectors and 1,305 are manufacturing firms.

3.2. Empirical strategy

Our dependent variables are binary indicators for product and process innovations. Ever since Schumpeter, it has been argued that product and process innovation are mutually dependent (Criscuolo *et al*. 2018). Firms often need to change their production process in order to develop new products or upgrade existing ones. Similarly, process innovations often enable firms to increase the quality of their existing products or to manufacture new products (Antonelli *et al*. 2012). When analysing the impact of technological collaboration on product and process innovations, Nieto and Santamaría (2010) apply a bivariate probit model and find that product and process innovations are dependent on each other. Amara *et al*. (2009) report complementarity between six innovation types (including product and process innovations) in Canadian KIBS by employing a multivariate probit model.

In order to analyse the impact of the breadth of external knowledge sources on product and process innovations, we consider the following bivariate probit model, which is a joint model of two binary dependent variables (Criscuolo *et al*. 2018).

$$y_1^* = \beta_1 x_1 + \varepsilon_1;\ y_1 = 1\ if\ y_1^* > 0;\ y_1 = 0\ if\ y_1^* \leq 0$$
$$y_2^* = \beta_2 x_2 + \varepsilon_2;\ y_2 = 1\ if\ y_2^* > 0;\ y_2 = 0\ if\ y_2^* \leq 0$$
$$(\varepsilon_1, \varepsilon_2) \sim BVN(0, 0, 1, 1, \rho)$$

Where y_1^* and y_2^* are latent variables, y_1 and y_2 are the dummy variables referring to the introduction of product and process innovations respectively, β_1 and β_2 are the coefficients on the independent variables x_1 and x_2 (the same in both equations) and ρ is the correlation between the error terms ε_1 and ε_2 which follow a bivariate normal distribution function (BVN) (for the explanation of the model see e.g. Greene, 2012). If product (y_1) and process (y_2) innovations are independent from each other, the error terms (ε_1 and ε_2) will be uncorrelated ($\rho = 0$) which means that the two equations can be estimated by two separate probit models (Criscuolo et al. 2018). However, if product and process innovations are correlated ($\rho \neq 0$), then estimating two separate probit models would yield consistent but not efficient estimates, because in that case the correlation between the error terms would be ignored (Cardamone, 2010).

3.3. Model specification

As mentioned above, the two dependent variables are binary indicators. Variable *Product innovation* is equal to 1 if a firm introduced new goods or services in the period 2014-2016, and zero otherwise. Similarly, variable *Process innovation* is equal to 1 if a firm implemented a new or significantly improved manufacturing/production process, distribution method, or support activity for goods or services, and zero otherwise (see Table 1 for a summary statistics). While product innovation focuses on the novelty of a new product, which should be validated by consumers and thus lead to higher revenues, process innovation is oriented towards cost reduction and thus production efficiency. From this perspective, greater price competition could motivate firms to focus on process innovation (Abrue *et al*. 2010; Terjesen and Patel 2017).

Our variable of interest is *Source_breadth*, which is constructed to capture the number of external knowledge sources (Laursen and Salter, 2006; Cainelli *et al*., 2020). As firms also reported the degree of importance for each source, we have taken into account two levels: high and medium (Ardito and Petruzzelli 2017; Criscuolo *et al*. 2018; Laursen and Salter 2014). That is, the variable is equal to zero for a source of no or low importance for each of the six external partners (suppliers, customers, competitors, universities, consultants and research centres) (Laursen and Salter, 2014), and is equal to six if a firm uses knowledge from all potential partners (Cronbach's alpha coefficient = 0.75). Following Criscuolo *et al*. (2018), these knowledge sources broadly correspond to economic agents and institutions that constitute a national innovation system.

With respect to control variables which capture firm and market characteristics, we include the following variables. *Firm size* is the number of employees in 2014. Variable *Labour productivity* is measured as turnover divided by the number of employees in 2014. *Export intensity* is measured as a percentage of firms' total revenues that came from sales in foreign markets in 2014 (see e.g. Radicic *et al*., 2019), while *R&D intensity* is measured as R&D expenditure divided by turnover in 2014 (see e.g. Laursen and Salter, 2014; Love *et al*., 2011). Because of a potentially limited role of R&D investment in the service sector (less than 1% in our full sample, see Table 1), other, complementary innovation input activities should also be included in the model, such as, training for innovation, design, acquisition of know-how and acquisition of technologically new equipment and machinery (Cainelli *et al*., 2020; Elche-Hotelano, 2011; Love *et al*., 2011). We control for all these activities. Acquisition of technologically new equipment and machinery is particularly important for the introduction of process innovations (Abrue *et al*., 2010), thus our models include a dummy variable *Acquisition of machines, equipment and materials* (see e.g. Silva *et al*., 2014). Variable *Training* is equal to 1 if a firm invested in in-house and/or external training in the context of product or process innovation, and zero otherwise (Cainelli *et al*., 2020; Leiponen, 2012; Silva *et al*., 2014). Variable *Acquisition of external know-how* is equal 1 if a firm invested in purchasing or licensing intellectual property rights, other intellectual property or other external knowledge for product or process innovation, and zero otherwise. Firms in the wholesale, retail, and hotel and restaurant sectors spend a significant amount of their innovation budgets on marketing (Abrue *et al*., 2010; Silva *et al*., 2014). This is captured by a dummy variable *Market introduction of new products* (see e.g. Cainelli *et al*., 2020; Silva *et al*., 2014). Design activities play a coordinating role in service sectors (Elche-Hotelano, 2011), so we included a dummy variable *Design*, equal to 1 if a firm invested in in-house and/or external procured design activities in direct connection to product or process innovation, and zero otherwise (see e.g. Love *et al*., 2011). Finally, sector effects are captured by eight dummies for each service sector in the sample (see Table 1).

Table 1 shows summary statistics for the full sample, as well as for subsamples of firms operating in KIBS, other services and manufacturing sectors. In the full sample, 34.5 per cent of firms introduced product innovation, while slightly less (27.9%) introduced process innovation. The largest number of innovative firms introduced both product and process innovation (438 firms or 17.5% of all firms), while 396 firms only introduced product innovation and 241 firms only engaged in process innovation. On average, firms use one external knowledge source. The modal firm on average has 77 employees. Labour productivity on average is 25.1 per cent. Firms in the sample have a low export intensity, such that only 13.1 per cent of sales comes from abroad. Slightly more than 1 per cent of turnover is invested in R&D activities. In terms of other innovation activities, the largest share of firms invested in machines and equipment (28.7%) and training for innovation (23%). Only a small share of firms invested in external know-how (8.8%), market launch of new products (13.5%) and design (13%).

INSERT TABLE 1 HERE

With respect to subsamples of service firms, summary statistics shows some marked differences between firms. Looking at innovation outputs, the share of KIBS firms that engaged in product innovation is more than double relative to their counterparts (37.2% versus 15.2%), while the difference is smaller for process innovation (29.3% versus 20%). According to Cainelli *et al*. (2020), KIBS firms are characterised by product, rather than process innovation, which is also the case in our sample, but the difference is not that large (37% of KIBS firms introduced product innovation, while 29% introduced process innovation). With respect to the innovation strategy, 137 firms or 21 per cent of all KIBS firms are complex innovators that introduced both product and process innovation. A single innovation strategy is adopted by 105 firms with respect to product innovation and 54 firms with respect to process innovation. In other service firms, the largest number of firms (61 firms or 13%) focused solely on process innovation, 35 firms only on product innovation, while 48 firms are complex innovators engaged in both types of innovation.

While KIBS firms use, on average, slightly more than one external knowledge source, this number is lower for other service firms (less than one or 0.58). The modal firm is larger in other services (80 employees) than in KIBS (54 employees). Concerning labour productivity, other services are slightly more productive than KIBS firms. However, exports intensity is the same for both categories. R&D intensity is much higher in KIBS than other services, as expected (1.55% versus 0.11%). Finally, a much higher share of KIBS firms invest in other innovation inputs than their counterparts. Namely, while 27.6 per cent of KIBS firms invest in physical capital, this share is smaller for other services (17.4%). The share of KIBS firms that acquire external know-how is double to the share of other services (11.8% versus 5.5%). The difference is even larger for training (30.7 % of KIBS firms versus 11%), market launch of new products (13.8% versus 3.7%) and design activities (12% versus 4%). Overall, we can conclude that KIBS firms are more innovative than other services in terms of both innovation inputs and outputs.

Finally, we look at the summary statistics for manufacturing firms. They are most innovative firms in the sample, whereby 41.3 per cent of firms introduced product innovation and 30.6 per cent process innovation. Regarding the number of complex innovators, 260 firms or 19.9 per cent of manufacturing firms simultaneously introduced both product and process innovations. The number of single innovators is 259 firms that only introduced product innovation and 126 firms that only introduced process innovation. The modal firm has 87 employees. Labour productivity, on average, is slightly larger than the sample average (27.7%), and export intensity is much higher compared to service firms (20.5%). R&D intensity on average is 1.26%, while 34% of manufacturing firms invested in physical capital for innovation (machines, equipment and materials).

4. Empirical results

The correlation matrix showing the Pearson correlation coefficients among the independent variables is presented in Table A1 in Appendix. The correlations are overall low to moderate suggesting that multicollinearity is unlikely to occur. The results from a bivariate probit model are shown in Table 2. The main results for the variable *Source_breadth* uniformly show an inverted U-shaped effect on both product and process innovation in the full sample as well as in the subsamples of KIBS, other services and manufacturing. These results provide support for *H1*. We will further investigate this result by estimating marginal effects below. But first we comment on the impact of control variables.

INSERT TABLE 2 HERE

Firm size has a positive effect on process innovation for KIBS firms. That is, large KIBS firms are more likely to introduce process innovation than their smaller counterparts. Labour productivity does not seem to have an effect on the probability of product and process innovations. Similarly, export intensity does not exert any effect on innovation outputs. R&D intensity increases the probability of product innovation ($p<0.01$) in the full sample, while in the subsamples, we can see that this result comes from the KIBS and manufacturing firms. This finding is in line with Amara *et al*. (2009), who note that R&D investment was among the key factors that increased the probability of product and process innovations in Canadian KIBS firms. Leiponen (2012) makes the same conclusion for Finish service sectors and even report the larger impact of R&D investment on innovative sales in service than manufacturing firms. A positive impact of R&D investment on manufacturing firms is in line with theoretical predictions. Investing in physical capital, as argued above, increases the likelihood of process innovation, for both KIBS firms but also firms in other services, while for manufacturing firms, this type of investment increased the probability of product as well as process innovations. Acquisition of external know-how does not seem to affect the likelihood of product and process innovations. Training for innovation has a positive and highly significant effect ($p<0.01$) on process innovation in KIBS and manufacturing firms, and marginally significant effect ($p<0.1$) on process innovation in other service firms. Investment in market launch, expectedly, has a positive and highly significant effect ($p<0.01$) on product innovation in all three subsamples. Similarly, design activities matter for product innovation, but more in other services than in KIBS and manufacturing firms (only marginally significant at the 10% level).

We also comment on the correlation coefficient ρ between the error terms in both equations. In the full sample, the correlation is equal to 0.098 and is statistically significant at the 5% level ($p<0.046$). If the coefficient is statistically significant, that implies that the error terms are correlated and that the two equations should be estimated jointly (Greene, 2012, p. 747). In other words, a correlation coefficient measures the correlation between the outcomes after the observed heterogeneity is taken into account (Radicic *et al.*, 2019). This means that product and process innovations have significant common unobserved factors; such that if a positive change in an unobserved influence increases the likelihood of product innovation then, via a positive correlation, it will increase the probability of process innovation too. In the subsample of KIBS firms, the correlation coefficient is also positive with the magnitude of 0.181, but only marginally significant ($p=0.056$). In the model for other service, the coefficient is still positive (0.183), but no longer statistically significant ($p>0.1$). A similar result is reported for manufacturing firms (ρ=0.056, but not statistically significant, $p>0.1$). However, given that the theory and empirical evidence (discussed in Section 2) point out the interdependence of product and process innovations, we report all results from bivariate probit models.

As mentioned above, we also estimate marginal effects for the variable of interest (*Source_breadth*) by calculating the changes in probabilities of introducing a particular type of innovation derived from a discrete increase (from zero to 1) in the variable of interest. To test the second hypothesis, we estimate three types of effects: a) on the probability of a simultaneous introduction of product and process innovations; b) on the probability that only product innovation would be introduced; and c) on the probability that only process innovation would be introduced. Figure 1 shows marginal effects for the full sample. We calculate pairwise comparisons of margins with the Bonferroni method to account for making multiple comparisons (at the 5% level of significance).[3] The comparisons show that, for a simultaneous introduction of product and process innovations, marginal effects are increasing and are statistically significant until the number of sources reaches three. Above this level of breadth, marginal effects continuously decrease. Similar results are found for firms that introduced only product innovation. However, an inverted U-shaped relationship between source-breadth and process innovation is not found. In contrast, marginal effects are continuously upward sloping, although the effects are not statistically different from each other, except when moving from no source to one source.

INSERT FIGURE 1 HERE

Overall, these results suggest that complex innovators, i.e. firms that simultaneously introduce product and process innovations experience increasing effects from using different knowledge sources, until they reach the tipping point of three sources. Qualitatively the same effect is reported for firms that engaged solely in product innovation. However, if firms only focus on process innovation, they benefit the same if they use only one source of knowledge or all five.

Now we focus on the marginal effects in subsamples. Figure 2 reports marginal effects for KIBS firms. The pairwise comparisons of margins (at the 5% level of significance) show qualitatively the same results as in the full sample, except for the case of only process innovation. That is, while the tipping point for the likelihood of the simultaneous introduction of both product and process innovations is three sources, in case of product innovation introduced without process innovation, the tipping point is one source. However, the exception is the case of only process innovation, in which marginal effects are statistically not different from each other, even when a firm uses no source of external knowledge.

INSERT FIGURE 2 HERE

Figure 3 shows marginal effects of *Source_breadth* variable for the subsample of other service firms. The pairwise comparisons of marginal effects show the same tipping point in case of joint introduction of product and process innovations as for KIBS firms. However, the probability of introducing only product innovation is not statistically different for any level of the source breadth. In other words, using external knowledge sources will not increase the

[3] Results are not presented, but available upon request.

probability of product innovation. For process innovation, the likelihood will increase if firms use one source. Although using more than one source increases their marginal effects, the difference is not statistically significant at any conventional level.

INSERT FIGURE 3 HERE

Finally, marginal effects for manufacturing firms are shown in Figure 4. For complex innovators, the tipping point is reached when firms use four knowledge sources. In other words, marginal effects of *source_breadth* increase until manufacturing firms use four sources, after which marginal effects start to diminish. For single innovators that engage only in product innovation, the tipping point is reached at three sources. However, for those manufacturing firms that only engage in process innovation, marginal effects are constantly increasing. While there are no statistical differences at 5% between marginal effects for one, two and three sources, the differences become significant for four, five and six sources. That is, using a broad pool of external knowledge sources is beneficial for those manufacturing firms that engage only in process innovation. In summing up, a broad knowledge pool is innovation-inducing in case of both complex and single innovators in manufacturing sectors, although it is most beneficial for manufacturing firms that solely engage in process innovation.

INSERT FIGURE 4 HERE

In summing up, overall results from looking at marginal effects of service firms provide support for *H2*, such that decreasing returns to external knowledge occur at different turning points depending on whether a firm is a complex innovator, thus introducing product and process simultaneously, compared to single innovators, focusing either on product or process innovation. While complex innovators experience increasing returns to external knowledge while utilizing quite a diverse pool of external knowledge, single innovators benefit the most from using one source of knowledge. However, *H2* is not supported for manufacturing firms. Namely, we found that both complex and single innovators in the manufacturing sector benefit from a broad knowledge pool, in particular firms exclusively engaged in process innovation. These results suggest that researchers investigating the impact of breadth of knowledge might adopt the demarcation approach and analyse manufacturing separately from service firms.

5. Conclusions and implications

This study explores the effectiveness of external knowledge sources (or inbound open innovations) on product and process innovations in German service sectors. Regarding the first hypothesis, empirical results from bivariate probit models suggest a non-linear, inverted U-shaped relationship between external knowledge sources and product and process innovations. These results are found for the full sample, as well as for the subsamples of KIBS, other services and manufacturing firms. More nuanced results are found when marginal effects are examined. The impact of external knowledge sources depends on whether firms simultaneously introduce product and process innovations or focus on only one type of innovation. In case of a joint engagement in product and process innovations, results uniformly show, for both KIBS and other services, that using up to three sources of knowledge increases the probability of simultaneous introduction of both types of innovation, while for manufacturing firms the turning point occurs at four sources. In other words, complex innovators benefit the most from using knowledge sources. But this beneficial effect decreases when firms use more than three sources (four in case of manufacturing firms). Accordingly, for complex innovators, our empirical findings are in line with the assimilation approach, given that we found rather similar influence of knowledge breath in both manufacturing and service firms.

For single innovators, which focus on one type of innovation, the effectiveness of inbound open innovation is heterogenous as it depends on the type of innovation introduced and sectors in which firms operate. For KIBS firms, single innovators, that engaged in product innovation, benefit the most from focusing on one external source of knowledge. However, in case of process innovation, decreasing returns occur as soon as a firm uses external knowledge sources. For other service firms, the results are opposite- product innovation is affected by decreasing returns from any number of knowledge sources, whereas process innovation benefits the most from one source. Compared to service firms, the impact of the breadth of knowledge has a distinct pattern for single innovators in manufacturing sectors. Namely, while those firms that engage solely in product innovation exhibit a very similar pattern as complex innovators, this is not the case for single innovators focusing on process innovation. These firms seem to benefit the most from the largest pool of knowledge, without experiencing diminishing returns. Considering this point, our findings support the demarcation perspective but only for the particular type of manufacturing firms – single innovators focused solely on process innovation.

Overall, these results provide support for the second hypothesis in case of service firms, insofar as complex innovation strategy requires the use of a diverse pool of external knowledge, while a single strategy does not benefit from the breadth of knowledge sources. However, in the case of manufacturing firms, the second hypothesis is partly supported, given that single innovators that focus on introducing process innovation benefits the most from using the maximum number of sources.

The main conclusion from our results suggest that the effectiveness of external knowledge sources is determined not so much by the degree of absorptive capacity, but rather by the type of innovation that is introduced. Based on the descriptive statistics of our data and the estimated coefficients on control variables, it can be deduced that KIBS firms have larger absorptive capacity than firms in other services. However, the impact of external knowledge sources is qualitative the same for both types of firms in case when they simultaneously introduce product and process innovations. The differential results emerge only when we consider individual innovation types. But the overall conclusion demonstrates that the breadth of external knowledge yields decreasing returns for firms that adopt a single innovation strategy. The exemption is the case of manufacturing firms that solely focus on process innovation. These firms should be further explored in future studies, as the empirical findings suggest that they do not seem to experience diminishing returns to knowledge breadth.

Previous studies that reported a curvilinear impact of external search explained the findings using the arguments related to absorptive capacity and the attention allocation theory. More specifically, the degree of absorptive capacity determines how much external knowledge a firm can absorb and exploit. Moreover, for each knowledge source that a firm wants to use, its managers and creative workers must dedicate a certain amount of time and effort. Based on these constraints and limited cognitive abilities, some innovative ideas and knowledge sources would not be fully exploited. Our findings can be explained with this reasoning, but more nuanced analysis revealed additional information that are not reported in previous studies, thus providing some managerial implications. Namely, searching widely, or using multiple external sources is beneficial to complex innovators, i.e. firms that simultaneously engage in product and process innovations. In contrast, for single innovators, searching widely entails decreasing returns once firms use more than one external knowledge source. In other words, over-search occurs if single innovators spread their absorptive capacity on two or more sources. While these results conform to service sectors, we found that opposite holds for manufacturing innovators engaged solely in process innovation. This finding is in line with Terjesen and Patel (2017), who find a positive, non-linear effect of knowledge search on process innovation in the UK manufacturing firms. However, this comparison is only partial, as Terjesen and Patel (2017) did not distinguish between single and complex process innovators. In general, our findings in relation to manufacturing firms are consistent with the seminar paper by Laursen and Salter (2006), insofar we found a curvilinear relationship between knowledge search and innovation performance. However, there is no point of comparison of our findings on single versus complex innovators in both service and manufacturing firms nor on a non-linear effect of knowledge search on innovation performance in service firms.

We briefly review the limitations of study, which can serve as suggestions for future research. Given that we use a cross-sectional data, it is difficult to draw strong causal inferences about the relationship between knowledge sources and firms' innovation performance. In other words, our analysis does not provide any direct evidence of causality. Availability of panel data would enable future studies to better understand the direction of the relationship as well as to control for the potential endogeneity of the variables (Leiponen, 2012; Love *et al.*, 2011; Rodriguez *et al.*, 2017) and modelling the persistence of innovation, that is well documented in a separate stream of research (see e.g. Ayllón and Radicic, 2019).[4] Another limitation of our study is that we focus on Germany, which is among the most innovative countries in Europe. It would be insightful to analyse other European countries and see whether our findings on the role of open innovation in the service sector would be confirmed. Finally, this study employs two innovation measures, that of product and process innovations. Non-technological, organizational and marketing, innovations are equally important for the service sector as product and process innovation, if not more important. Therefore, future studies could investigate the role of external knowledge in fostering non-technological innovations.

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[4] Generalisation of our findings is not limited by the use of cross-sectional data, given that the surveyed firms are a representative sample of German firms.

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APPENDIX

INSERT TABLE A1 HERE

Tables and figures

Table 1. Descriptive statistics

Variables	Full sample (N=2,501)		Knowledge intensive business services (KIBS) (N=651)		Other services (N=545)		Manufacturing sectors (N=1,305)	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
Product innovation	0.345	0.476	0.372	0.484	0.152	0.360	0.413	0.493
Process innovation	0.279	0.449	0.293	0.456	0.200	0.400	0.306	0.461
Source breadth	1.142	1.534	1.192	1.578	0.583	1.189	1.349	1.584
Firm size	76.908	131.959	54.092	118.682	79.537	129.395	87.192	137.875
Labour productivity	0.251	0.172	0.204	0.140	0.247	0.203	0.277	0.167
Export intensity	0.131	0.232	0.052	0.156	0.051	0.167	0.205	0.261
R&D intensity	1.087	3.174	1.549	4.036	0.112	0.883	1.264	3.215
Machines, equipment and materials	0.287	0.453	0.276	0.448	0.174	0.380	0.340	0.474
Acquisition of external know-how	0.088	0.284	0.118	0.323	0.055	0.228	0.087	0.282
Training	0.230	0.421	0.307	0.462	0.110	0.313	0.241	0.428
Market launch of new products	0.135	0.342	0.138	0.345	0.037	0.188	0.175	0.380
Design	0.130	0.336	0.120	0.325	0.040	0.197	0.172	0.378
Knowledge intensive business services (KIBS)								
Media services	0.054	0.225	0.118	0.323				
IT and telecommunications	0.098	0.297	0.171	0.376				
Banking and insurance	0.031	0.173	0.132	0.339				
Technical and R&D services	0.044	0.206	0.312	0.464				
Consulting and advertisement	0.034	0.182	0.267	0.443				
Other services								
Wholesale	0.081	0.273			0.245	0.431		
Transport equipment and postal services	0.070	0.254			0.450	0.498		
Firm-related services	0.066	0.249			0.305	0.461		
Manufacturing								
Manufacture of food products, tobacco	0.061	0.240					0.117	0.322
Textiles, clothing and	0.041	0.199					0.079	0.270

leather products						
Wood, paper, printing	0.034	0.181			0.065	0.247
Refining petroleum, coke manufacture, chemical industry	0.038	0.190			0.072	0.259
Manufacture of rubber and plastic products	0.040	0.195			0.076	0.265
Glass, ceramics, other non-metallic mineral products	0.028	0.166			0.054	0.227
Manufacture of basic metals and fabricated metal products; steel, metal structures	0.091	0.287			0.174	0.379
Manufacturing of office machinery and computers, electrical machinery and apparatus; radio, television and communication equipment and apparatus	0.074	0.262			0.142	0.349
Manufacturing of machinery, weapons and ammunition, domestic appliances	0.041	0.199			0.079	0.270
Manufacturing of furniture, jewellery, musical instruments, sports equipment, games and toys	0.074	0.262			0.142	0.349

Table 2. Estimations from bivariate probit models

Independent variables	Full sample		KIBS		Other services		Manufacturing sectors	
	Product innovation	Process innovation	Product innovation	Process innovation	Product innovation	Process innovation	Product innovation	Process innovation
Source_breadth	1.049***	0.726***	1.008***	0.921***	0.946***	1.059***	1.114***	0.499***
	(0.068)	(0.066)	(0.135)	(0.135)	(0.189)	(0.177)	(0.092)	(0.086)
Source_breadth squared	-0.160***	-0.105***	-0.138***	-0.152***	-0.141***	-0.155***	-0.181***	-0.058***
	(0.014)	(0.013)	(0.023)	(0.025)	(0.043)	(0.040)	(0.020)	(0.018)
Firm size	0.000	0.000	0.001	0.001***	0.001	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
Labour productivity	-0.092	0.342	0.048	0.582	0.379	0.518	-0.255	0.154
	(0.244)	(0.228)	(0.541)	(0.450)	(0.526)	(0.582)	(0.323)	(0.313)
Export intensity	0.123	-0.157	-0.489	-0.650	0.185	-0.474	0.278	0.104
	(0.187)	(0.176)	(0.517)	(0.499)	(0.509)	(0.667)	(0.220)	(0.204)
R&D intensity	0.098***	0.011	0.091***	0.025	0.023	-0.021	0.121***	0.006
	(0.018)	(0.012)	(0.024)	(0.019)	(0.077)	(0.064)	(0.031)	(0.015)
Machines, equipment and materials	0.278***	1.093***	0.292	0.672***	0.304	1.639***	0.236**	1.186***
	(0.089)	(0.081)	(0.180)	(0.168)	(0.229)	(0.228)	(0.118)	(0.105)
Acquisition of external know-how	0.095	-0.027	-0.046	0.076	-0.031	-0.107	0.203	-0.104
	(0.130)	(0.114)	(0.230)	(0.195)	(0.337)	(0.359)	(0.190)	(0.158)
Training	0.140	0.509***	0.200	0.746***	0.223	0.505*	0.059	0.393***
	(0.098)	(0.090)	(0.176)	(0.166)	(0.282)	(0.273)	(0.133)	(0.119)
Market launch of new products	0.909***	0.076	0.901***	0.177	1.881***	-0.184	0.845***	0.158
	(0.132)	(0.109)	(0.243)	(0.196)	(0.633)	(0.444)	(0.169)	(0.137)
Design	0.401***	-0.090	0.456*	0.127	1.290***	-0.150	0.299*	-0.154
	(0.126)	(0.109)	(0.248)	(0.203)	(0.430)	(0.411)	(0.160)	(0.137)
Constant	-1.757***	-1.696***	-1.618***	-1.845***	-2.097***	-1.778***	-1.582***	-1.771***
	(0.097)	(0.095)	(0.239)	(0.222)	(0.198)	(0.181)	(0.139)	(0.158)
No of observations	2,501	2,501	651	651	545	545	1,305	1,305

Notes: Robust standard errors in parentheses. Sectoral dummies included, but not reported. The reference industry category for the full sample and manufacturing sectors is Manufacture of food products and tobacco. For KIBS the reference category is Media services, while for other services the reference category is Transport equipment and postal services. *** *p<0.01,* ** *p<0.05,* * *p<0.1.*

Figure 1. Marginal effects for the full sample

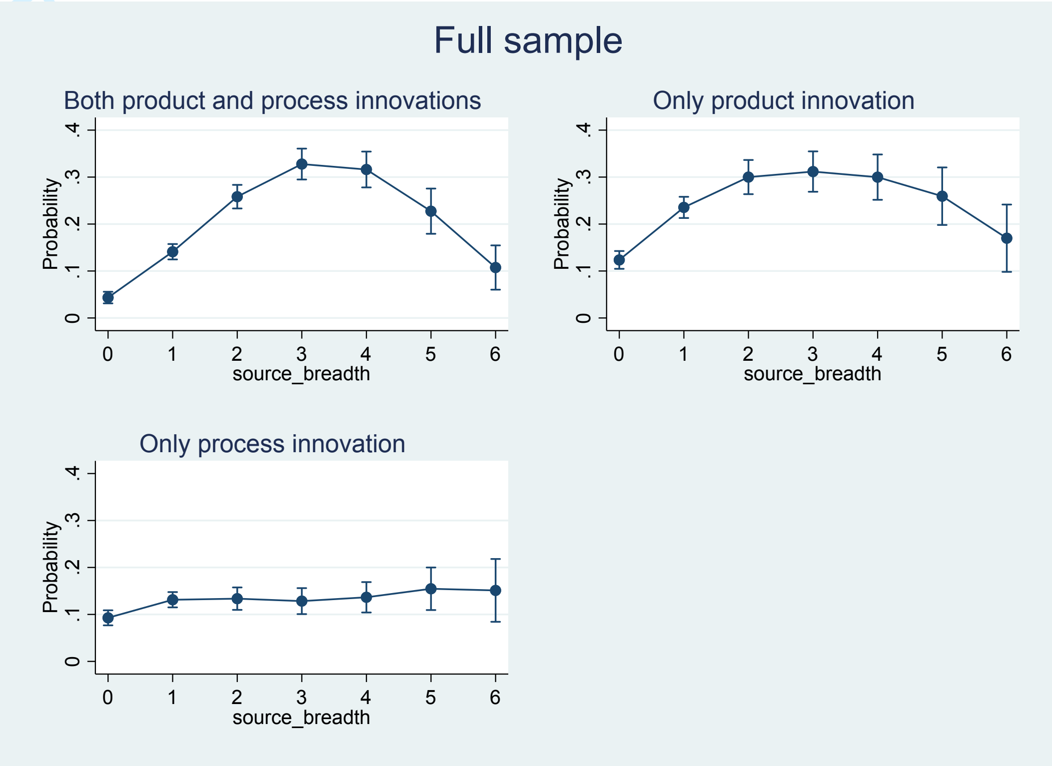


Figure 2. Marginal effects for KIBS firms

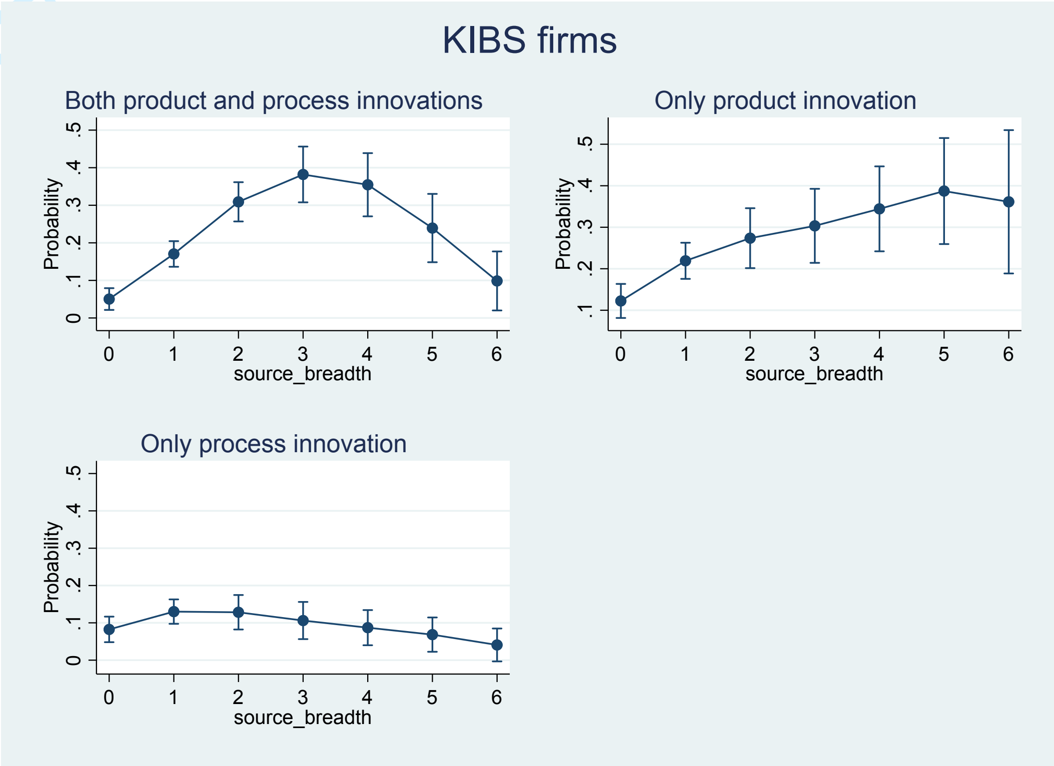
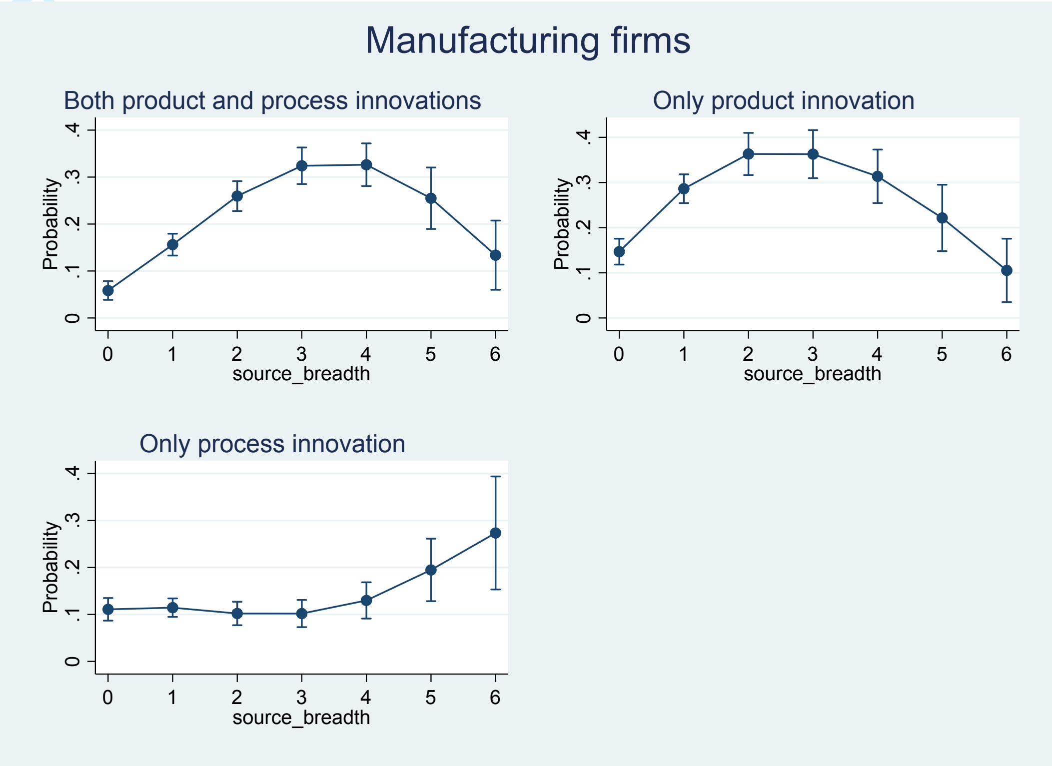


Figure 3. Marginal effects for other service firms

Figure 4. Marginal effects for manufacturing firms



Appendix

Table A1. Correlation matrix

Variables	1	2	3	4	5	6	7	8	9	10
1. Firm size	1.000									
2. Labour productivity	0.094	1.000								
3. Export intensity	0.010	0.240	1.000							
4. R&D intensity	-0.041	-0.082	0.198	1.000						
5. Machines, equipment and materials	0.117	0.044	0.028	0.232	1.000					
6. Acquisition of external know-how	0.059	0.064	0.016	0.135	0.387	1.000				
7. Training	0.053	0.004	0.052	0.235	0.447	0.346	1.000			
8. Market launch of new products	0.086	0.059	0.081	0.254	0.285	0.229	0.386	1.000		
9. Design	0.018	0.017	0.021	0.178	0.232	0.221	0.357	0.402	1.000	
10. Source breadth	0.151	0.046	0.084	0.382	0.572	0.375	0.554	0.384	0.348	1.000

Notes: *** $p < 0.01$; ** $p < 0.05$, * $p < 0.1$.