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Original Article

What determines the size of contract research from firms to universities? The role of geographical distance and regional co-location

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Abstract

This article explores the role of geographical distance and regional co-location as a determinant of the size of contract research from firms to domestic universities. The analysis relies on a panel of three consecutive R&D surveys for Belgium, and controls for firm, university, and network characteristics. The findings reveal that firms tend to enter into larger-sized contract research with universities that are either located nearby or farther away. Regional co-location is also positively associated with the size of contract research from firms to universities.

JEL classification: L14, L24, O32, R12

1. Introduction

Innovative activities are becoming increasingly complex and firms are forced to look for external knowledge and maintain relationships with various external organizations (Huggins *et al.*, 2008; Spithoven *et al.*, 2013), among which universities play a central role (Caniëls and van den Bosch, 2011). Firms maintain many different relationships with one or various universities (D'Este and Patel, 2007; Bekkers and Bodas Freitas, 2008; Thursby and Thursby, 2011; Ramos-Vielba and Fernández-Esquinas, 2012), and have an array of transfer channels at their disposal to access university research (Cohen *et al.*, 2002) among which contract research occupies a highly prominent place (Agrawal, 2001; Ramos-Vielba and Fernández-Esquinas, 2012).

The focus in this article is on contract research between firms and universities, where universities sell new or existing research results to firms, engage in R&D consulting activities, and/or offer help in solving ad hoc scientific or technical problems (D'Este and Patel, 2007; Bekkers and Bodas Freitas, 2008). In this article, contract research is defined in line with the OECD Frascati manual (OECD, 2015) and includes all expenditures spent on R&D that is performed by external organizations which, in this case, refer to domestic universities. Contract research includes sponsored or commissioned research as well as payments for collaborative efforts, as long as this collaboration is covered by a formal contract. Commissioned research covers all university research performed by academic personnel

on behalf of firms to be readily applicable to them (Bekkers and Bodas Freitas, 2008). Typically, contract research covers a specific research project or projects, and defines the roles and responsibilities of the partners—firms and universities—involved in these projects. This definition contrasts with that used by Bodas Freitas *et al.* (2013) in that testing and consulting might be included in contract research only as long as there is an R&D component to them. Contracts describe the work to be undertaken; the share of technical, commercial, and economic risks of each party; treat the publication rights of results and the ownership and usage of the research results; and deal with the financial aspects. Contract research captures formalized market relations giving rise to monetary flows (Trippl *et al.*, 2009; Mowery and Ziedonis, 2015). The expenditures are restricted to R&D activities that is, "creative and systematic work undertaken in order to increase the stock of knowledge—including knowledge of humankind, culture and society—and to devise new applications of available knowledge" (OECD, 2015: 44).

The relevance of studying firms' contracting research to universities should be seen in the context of the growing body of literature on industry–university interactions (Meyer-Krahmer and Schmoch, 1998; Schartinger *et al.*, 2002; Muscio *et al.*, 2015) and policy makers' interest in the subject (OECD, 2002).

The article meets the call from D'Este and Patel (2007), reiterated by D'Este and Iammarino (2010), to do further research on the variety of relationships and knowledge transfer mechanisms between firms and universities. Notwithstanding the broad interest empirical studies display in firm–university knowledge transfer, the practice of contract research by universities remains insufficiently studied as a particular source of knowledge (Agrawal, 2001; Bodas Freitas *et al.*, 2014). This article contributes to the debate by focusing on this particular market mediated relationship between firms and universities: that is, contract research.

Most research up to now deals with contract research as a dichotomous value, leaving no room for the contract size (e.g. D'Este *et al.*, 2013; Drejer and Østergaard, 2017). As far as we are aware, there is no literature investigating the relationship between distance and the size of contract research in firm–university linkages. Perkmann *et al.* (2011) look at the amount of money involved in contract research, but do not discuss the impact of geographical distance. Bodas Freitas *et al.* (2014) consider the amount of contract research but limit themselves to the (non-)regional firm–university linkages and discard the impact of geographical distance. Similarly, the debate on firm–university interactions remains unclear on the appropriate spatial scale of knowledge exchange (Grillitsch and Trippl, 2014). Malmberg and Power (2005) demonstrated that market mediated relations reach beyond the regional scale because they target complementary competences and knowledge. Hence, contract research is also expected to occur over large distances. However, Laursen *et al.* (2011) argued that contract research, when keeping the quality of university research constant, preferably goes to universities that are located nearby. The main reason for this geographical preference lies in the fact that large parts of knowledge are tacit (Cowan *et al.*, 2000; Gertler, 2003; D'Este *et al.*, 2013).

This article intends to fill this gap and focuses on two spatial dimensions that might affect the size of contract research to universities: the geographical distance between firm and university (e.g. Laursen *et al.*, 2011; Hewitt-Dundas, 2013); and their regional co-location (e.g. Broström, 2010; Balland and Rigby, 2017).

The article is organized as follows. Section 2 gives an overview of the literature in order to outline the context and rationale of contract research and presents the determinants that help explaining the size of contract research. Data and variables are reviewed in Section 3. Section 4 reports the analytical findings. The final section summarizes the most salient findings, sums up the limitations, and proposes future research topics.

2. Literature review and hypotheses

2.1. The importance of contract research to universities by firms

Contract research illustrates a university's entrepreneurial character because of generation of income through the formalization of knowledge flows in a contractual context (D'Este and Perkmann, 2011). Contract research has been studied using insights from surveys of university staff (Gulbrandsen and Smeby, 2005; Link *et al.*, 2007; D'Este and Perkmann, 2011). D'Este and Patel (2007: 1302) conducted a survey of 1,528 academics in the UK and reported that 56% of university researchers engaged in consultancy or contract research.

Another approach takes administrative databases at universities as a starting point (Perkmann *et al.*, 2011; Muscio *et al.*, 2015). Perkmann *et al.* (2011: 542) reported that university income from contract research in the UK is 15 times the size of income from intellectual property rights; and even 21 times when the revenue from consulting activities is included. These databases however only record monetary flows registered by the university itself, and do

not take into account other possible channels used by university staff for commercializing research. Informal relations between academic personnel and industry is estimated to be substantial (Arza and Carattoli, 2017). As such, it comes as no surprise that Bodas Freitas *et al.* (2013) found that limiting research to university databases overlooks >50% of university–industry linkages.

2.2. Contract research and geographical distance between firm and university

Geographical distance is known to play a key role in innovation, but its exact role remains ambiguous (Broström, 2010). Uyarra (2010) reported little conclusive evidence of a distance decay effect across the multiple channels of interaction, even if some linkages by firms are more local than others.

2.2.1. Small geographical distances and contract research: the local dimension

The relevance of small geographical distances for knowledge exchange, highlighting the local dimension, is discussed through four viewpoints. First, the theoretical insights from transaction cost economics posit that contract research needs to be negotiated and monitored (Spithoven and Teirlinck, 2015). Because the transaction cost argument rests on efficiency assumptions (Holcomb and Hitt, 2007), universities that are located in the vicinity of the firm are a preferred partner because proximity not only minimizes costs but also reduces uncertainty and opportunistic behavior. Nearby universities, therefore, are more trusted to handle contracts for higher amounts of money than universities that are located further away.

Second, drawing on the local knowledge spillover model to identify the reasons firms choose to work with universities in the vicinity, Fitjar and Gjelsvik (2018) argue that, even though it might be better to opt for distant universities offering higher quality research, three reasons play in favor of contracting out research to nearby universities. First, proximity facilitates spillovers since knowledge transfer across distance is costly, and local linkages reduce the risk of information loss in knowledge transfer. Second, firms do not necessarily enter into the time consuming process of searching for universities offering the best possible knowledge. The search mostly starts at the local level, and firms tend to be satisfied with a local, known university offering knowledge of a sufficient nature rather than looking further afield for state of the art expertise. Third, contracting out to local universities contributes to the research capacity at local level. Other local parties may benefit as well, because of the creation of positive externalities in the form of new local knowledge or the local introduction of new techniques (Laursen *et al.*, 2012). Firms, like universities (Uyarra, 2010), are increasingly engaged in their region. Based on this line of thought, it is to be expected to find contract research involving larger amounts of money involving nearby universities.

Third, Asheim and Isaksen (2002) claimed that local knowledge relations are difficult to match for more distant relationships. A decade later, Isaksen (2009) again emphasized that useful knowledge is local and unique, strengthening the importance of small geographical distances. The diverse nature of knowledge itself—tacit versus codified—leads to ambiguous interpretations with respect to geographical distance (Cowan *et al.*, 2000; Gertler, 2003). Because not all knowledge can be codified and transmitted, the need for personal contact remains important, stimulating firms to buy the required research results from nearby located universities (Döring and Schnellenbach, 2006; Laursen *et al.*, 2011). Moreover, the costs of codification play a role as well (Cowan *et al.*, 2000). Therefore, the tacit nature of knowledge is an explanation for the geographically bounded nature of spillovers (Arundel and Geuna, 2004; Mowery and Ziedonis, 2015). Arundel and Geuna (2004) empirically confirmed that the relation between firms and public research organizations (universities among them) is significantly affected by smaller geographical distances. Paci and Usai (2009) demonstrated declining knowledge transactions when geographical distance increases. Small geographical distances are posited to favor the amount of contract research (Broström, 2010; Laursen *et al.*, 2011).

Fourth, scholars emphasize micro-geographical linkages to justify the choice for nearby and regional universities (Bodas Freitas *et al.*, 2013; Perkmann *et al.*, 2013). It is more convenient for researchers within firms to know and contact professors with whom they are already familiar. This line of thought considers the prior experiences of students at their universities to be behind localized trust (Landry *et al.*, 2002), which translates into larger-sized research contracts. Former university students not only acquire professional training, they are also familiar with the norms and values of a specific university (Drejer and Østergaard, 2017). Social ties developing between former students and university staff might play a decisive role in increasing mutual trust and social capital (Breschi and Lissoni, 2001), enhancing the size of contract research amounts.

2.2.2. Large geographical distances and contract research: the pipeline dimension

However, drawing on the resource-based view, firms search for complementary knowledge and technical sources wherever available (D'Este and Iammarino, 2010; Spithoven and Teirlinck, 2015). Firms see universities as unique sources of complementary knowledge and technology (Morandi, 2013). Berchicci *et al.* (2016) argue that distant collaborations raise firms' expectations to find complementary knowledge and more diverse partners, especially if more radical knowledge is involved. The resource-based view suggests that firms are eager to complement their internal and unique resources with the best knowledge available (Holcomb and Hitt, 2007), irrespective of its location. If this knowledge is not available at nearby universities, R&D active firms are bound to look for them at larger distances, and are willing to pay higher amounts for it. When sourcing R&D from further away, the acquiring firm should trust its source particularly well, highlighting the element of trust in, and reputation of, universities. If distant contract research is ordered, the combination of needing the unique knowledge and trust allow for increasing the spending on contract research.

Various scholars stress the relevance of interplay between local networks and broader pipelines in inter-organizational knowledge transfer (Bathelt *et al.*, 2004; Waxel and Malmberg, 2007; Malecki, 2010). As argued by Bathelt and Henn (2014), firms are increasingly pushed to tap into distant knowledge sources and networks. However, firms forging distant linkages would, therefore, only engage with distant universities if the required knowledge is located there (Huggins *et al.*, 2008; D'Este and Iammarino, 2010; Berchicci *et al.*, 2016). Arguments in favor of contract research over longer distances are the availability of highly talented researchers at lower cost (Huggins *et al.*, 2008), and the presence of universities that are helpful with more ground-breaking innovation (D'Este and Iammarino, 2010; Fu and Li, 2016). More distant knowledge is deemed superior to locally available knowledge, and contract research to more distant universities could be supposed to be induced by universities better equipped to convey complex knowledge across larger distances (Lissoni, 2001). These universities can be expected to be consulted for complex knowledge; either when there are no local alternatives to obtain that knowledge (Fu and Li, 2016); or if the university research results are cheaper (Maskell *et al.*, 2007; Herstad *et al.*, 2014). Knowledge developed at distant universities shows more variety (regional environments reduce the variety of knowledge, as the pool of knowledge risks becoming familiar but potentially redundant), and with distance the scope of available knowledge increases (Berchicci *et al.*, 2016). Therefore, complementary knowledge is more likely to be located in distant places (Berchicci *et al.*, 2016).

Based on the considerations in favor of the local or the pipeline dimension the relation between size of contract research and geographical distance is expected to be curvilinear, emphasizing higher amounts spent by firms for contracts with nearby universities and distant universities selling relevant knowledge. Hence, the following hypothesis is formulated:

H1: The size of contract research will be curvilinear U-shaped related to the geographical distance between firm and universities.

2.3. Contract research and regional co-location of firms and universities

In addition to geographical distance, regional co-location is thought conducive to the likelihood of university–industry interactions (Caniëls and van den Bosch, 2011; Casper, 2013). A high number of network possibilities, or high levels of social capital, reinforce opportunities to learn from contract research (Laursen *et al.*, 2012). Regional co-location points to the existence of "sticky" knowledge that is hard to capture and absorb for firms located outside the region. Azagra-Caro *et al.* (2006) and Miguélez and Moreno (2015) state that absorptive capacity in the regional environment helps in the uptake of university research. Casper (2013) argues that the quality of the regional environment influences the commercial use of university research. Berchicci *et al.* (2016), therefore, point to the fact that knowledge flows within a region are superior to the ones crossing regional boundaries. Co-located relations potentially facilitate tapping into knowledge repositories, expertise and skills (Bathelt *et al.*, 2004; Malecki, 2010) that are difficult to reproduce in other regions (Asheim and Isaksen, 2002).

Regionally co-located firms and universities share a similar institutional context with shared norms, values, language, and laws; which facilitate the exchange of knowledge (Agrawal and Cockburn, 2003; Gertler, 2003; Waxel and Malmberg, 2007; Marrocu *et al.*, 2013). Co-location also helps establishing a shared interpretative framework facilitating the ability to learn (Berchicci *et al.*, 2016). These institutional contexts are characterized by territorial

innovation models, like the regional innovation systems (Cooke *et al.* 1997; Caniëls and van den Bosch, 2011). Regional innovation systems refer to spatial entities possessing autonomous political power (Cooke *et al.*, 1997; Asheim and Isaksen, 2002; Uyarra, 2010). Cooke *et al.* (1997) consider the regions in Austria, Belgium and Germany as examples of strong regional innovation systems. Alternatively, the notion of industrial districts points to a similar existence of integrated networks, common traditions, facilitated access to complementary knowledge, enhanced knowledge exchange through collaboration, homogenous institutions and communities, etc. (Gordon and McCann, 2000).

According to Casper (2013), the creation of qualitative dense research environments facilitates knowledge exchange. Spatial concentrations bring a shared knowledge base in their wake (Manning, 2013; Berchicci *et al.*, 2016). This revived an interest in the insights on economies of agglomeration—especially with respect to the ease of knowledge exchange within a particular spatial scale (Gordon and McCann, 2000; Waxel and Malmberg, 2007). The idea is that technology clusters are characterized by regional concentration of R&D expertise (spin-offs, R&D departments in large firms, ...) and highly skilled labor, but also the presence of universities performing relevant research and open to sharing this with the business environment (Manning, 2013).

Administrative regions are often considered a proxy of institutional contexts (Fitjar and Huber, 2015; Roper *et al.*, 2017). These regions are frequently used when studying knowledge exchange (Grillitsch and Trippl, 2014; Balland and Rigby, 2017) and spillovers (Paci and Usai, 2009; Marrocu *et al.*, 2013). For example, Agrawal and Cockburn (2003), use USA and Canadian metropolitan statistical areas to give evidence on effects of co-located firms and universities (see also Huggins *et al.*, 2008; Balland and Rigby, 2017); and Marrocu *et al.* (2013) use NUTS (Nomenclature of Territorial Units for Statistics) regions. However, the exact spatial scale varies according to the type of firm–university linkage. In their account of the Austrian automotive sector, Grillitsch and Trippl (2014) posit that contract research between firms and universities occurs mostly at regional (and national) level conditional on the presence of universities within the region.

Another reason favoring regional co-location is that it facilitates coordination and monitoring by firms and universities. Holcomb and Hitt (2007) point to the firm's weakness to counter opportunism as academic partners may decide to use to disclose the research results to others, thus increasing monitoring costs. After all, the firm has to disclose parts of its ideas or technology to academic researchers to ensure that the results are usable (Santoro and Gopalakrishnan, 2001). Inter-organizational trust, based on social norms and values embedded in regions, makes firms and universities abstain from opportunistic behavior (Klein Woolthuis *et al.*, 2005).

Due to the arguments cited above—a high level of social capital, a similar institutional context, shared norms and values, and disclosure of ideas or technology—regional co-location is inductive to inter-organizational trust. Inter-organizational trust is important throughout the whole process of contract closure, project execution (e.g. meeting deadlines or producing the correct deliverables) and exploitation of the results (Klein Woolthuis *et al.*, 2005); Santoro and Gopalakrishnan, 2001). As firms' confidence in their university partner increases, so does the size of contract research because firms are unwilling to take unnecessary risks.

Based on the previous arguments it is expected that, when firms and universities are located in the same region(al innovation system), the level of inter-organizational trust and possibilities of interaction are higher, increasing the size of contract research. Therefore, the following hypothesis is formulated.

H2: The size of contract research will be higher when firm and university are located in the same region.

3. Data and variables

3.1. Databases

The analysis draws on two separate, but related, databases. First, the OECD business R&D survey is directed at all R&D active firms operating in Belgium. The R&D data for the period 2004–2009 are collected in three consecutive waves (2006–2008–2010) since the R&D survey is organized every 2 years. The OECD business surveys include a question concerning the amount, partner type, and partner location of all external R&D expenditure (contract research). Our focus is on contract research performed by universities on behalf of firms. Second, the OECD non-profit R&D survey targets all non-profit organizations in a separate annual questionnaire. Apart from universities, these

organizations are collective and public research centers; university colleges; and private non-profit organizations. These sources are used to characterize universities in terms of research capacity, research performance in terms of publications, and applied sciences (see further). Both R&D surveys follow the guidelines of the OECD Frascati Manual to ensure that definitions are the same across regions, countries and performers (OECD, 2015). The surveys are directed to the entire known population of R&D active firms and non-profit organizations.

The business R&D surveys reveal information on 674 contract relationships by 460 firms. However, contracts with universities abroad and contract descriptions with missing values were omitted. There is complete information on 363 contract relationships with domestic universities by 287 firms. These contracts are used in the subsequent analyses.

The representativeness of the reduced sample is tested (using t-tests and Pr-tests—see Appendix Table A1) and there is no significant difference in terms of the size of contract research. In terms of the spatial dimensions, there is no difference in the case of geographical distance, but there is a significant difference in terms of regional co-location which is higher in the retained sample. Moreover, in the sample of 363 contract relationships the included firms are less present in science-based industries. The universities involved are significantly less performant and less specialized in applied sciences when compared with the population.

Figure 1 provides an overview of the location of the firms (black dots) and the universities including their satellite campuses (gray dots) in Belgium. Figure 1 shows that there is in fact always a university nearby. Yet, as was clear from the literature review, not all firms will contract their research out to the nearest university (or its satellite).

3.2. Variables

3.2.1. Dependent variable

The size of research contract firms enter into with universities is calculated as a transaction between a firm and the respective university based on the contract research to that specific university reported by the firm and expressed in euro. The unit of analysis is the individual contract research agreement between firms and universities. For each case of contract research the benefitting university is known. Because of the existence of a left skewed distribution with many firms spending small amounts of money and a few spending large amounts, the dependent variable is expressed in logarithmic terms. In this context an ordinary least square regression is appropriate. In order to check the robustness of our findings, we have also applied quantile regression on the median size of contract research, but the results did not vary.

3.2.2. Independent variables

In line with the two central research questions, two independent variables are used in the analyses. The first independent variable is the geographical distance, which is captured in terms of km. The street addresses of firms and

Figure 1. Map of Belgium with firms (black) having contract research with universities and their affiliates (gray).

universities are entered and the distances calculated using a route planning software program. This measure differs from studies using a distance measure "as the crow flies" (e.g. Laursen *et al.* 2011), or studies that proxy km, such as de Jong and Freel (2010) or Berchicci *et al.* (2016), for example, by equating co-location in the same city as being 1 km. Distance is used in its logarithmic transformation (LDIST) because of skewed values. In order to account for the hypothesized non-linear relation between distance and size of contract research, the square of distance is included as a variable (LDISTsq).

Reviewing the empirical research shows that the number of studies using geographical distance is limited (see e.g. Laursen *et al.*, 2011). In the context of the USA, Döring and Schnellenbach (2006) reported studies pointing to an average of 80.5 km where the university acted as a source of new knowledge. Based on patent data for 12 EU countries, Petruzzelli (2011) calculated that the average distance between firms and universities is 50 km. Hewitt-Dundas (2013) cited research that limited the positive effect of university research on innovative activities to 120 km in the USA and 100 km in Germany. Berchicci *et al.* (2016) recount that, in the Dutch case, knowledge spillovers reach up to 300–400 km for small high tech firms.

The second independent variable considers regional co-location. As documented by the innovation systems literature on countries and regions (Cooke *et al.*, 1997; Döring and Schnellenbach, 2006; Caniëls and van den Bosch, 2011; Roper *et al.*, 2017), the spatial organization in a bordered territory matters. To investigate this spatial dimension, regional co-location in the same administrative region of a firm and university having contract research has been added in the analysis (REGION). This co-location can be entered in addition to the geographical distance. A well-known geocode standard in this case is the Classification of Territorial Units for Statistics, also known as NUTS, used by Eurostat (see e.g. Paci and Usai, 2009). At Belgian level, it is meaningful to study this regional level at NUTS 1 for two reasons. First, the majority of industrial policy is regionalized according to this classification. Second, the possibility to acquire university research also depends on university regulation (Muscio *et al.*, 2015). University regulation, because of a regionalized educational policy, also differs for each of the three regions in Belgium, corroborating that the NUTS 1 level is a relevant spatial dimension for Belgium (Belgian Science Policy Office, 2010), as it is in other countries such as the UK (D'Este and Iammarino, 2010). The three regions considered are: the Brussels-Capital Region, the Flemish Region in the North, and the Walloon Region in the South.

3.2.3. Control variables

Being close to each other, in terms of geographical distance or regional co-location, does not guarantee knowledge exchange (Waxel and Malmberg, 2007; Spithoven and Teirlinck, 2015). Also firm characteristics are known to play a role, as are—less studied—university (Agrawal, 2001; D'Este and Iammarino, 2010; D'Este *et al.*, 2013), and network (Roper *et al.*, 2017) characteristics.

First, specific knowledge requirements depend on various firm characteristics. The analyses include a vector of control variables: size, age, foreign control, sector, R&D intensity, and regional funding. Firm size is, in general, an important predictor of R&D activities and is measured as the number of employees in fulltime equivalent. Small firms require more routine services and consultancy which are likely to be acquired from their local university (Siegel *et al.* 2007). Large firms are more attracted by (distant) universities because of their reputation for excellent research in a particular area of interest. The measurement is done in logarithmic terms (LSIZE). Age is the second control variable. Young R&D active firms are often characterized by a lack of knowledge resources making them more inclined to look elsewhere for it (Spithoven and Teirlinck, 2015). The firm might be foreign controlled and be part of a multinational group (GROUP). University research can be used to supply knowledge on locational preferences or to fuel the knowledge of the home base. Sector activity is of importance because of differences in knowledge requirements (Marsili and Verspagen, 2002). Many studies in the field of industry–university relations focus on one particular sector. Agrawal and Cockburn (2003) look at electrical engineering in 254 metropolitan areas in the USA and Canada; Waxel and Malmberg (2007) zoom in on the biotech sector in Uppsala (Sweden); and Trippl *et al.* (2009) focus on the software sector in Vienna (Austria). Following other authors, such as D'Este and Iammarino (2010), this article aims to perform a generalized research over all sectors. The analysis, therefore, uses the taxonomy developed by Marsili and Verspagen (2002) and corroborated by analyses performed by Bekkers and Bodas Freitas (2008) and Spithoven *et al.* (2013). Use is made of the international standard industrial classification (ISIC codes) to classify all activities into sectors. For R&D active firms looking for university knowledge this classification justifies the focus on

the knowledge intensive (SECT-KI) and science-based (SECT-SB) sectors, using all other sectors as reference categories.

When acquiring contract research from universities, the need for absorptive capacity makes itself felt (de Jong and Freel, 2010). Absorptive capacity stems from prior knowledge and having higher levels of it increases the likelihood to recognize, assimilate, use, and exploit knowledge from university research (Spithoven *et al.*, 2013). R&D intensity is often used as a proxy for the firms' knowledge base (Herstad *et al.*, 2014) or absorptive capacity (Arundel and Geuna, 2004; Berchicci *et al.*, 2016). R&D intensity reflects the relative importance of R&D activities compared with other activities of the firm. R&D intensity is measured as the amount of R&D expenditures by firms divided by the turnover in the same period. R&D intensity is expressed in logarithmic terms (LRDINT) to facilitate the interpretation of the estimated coefficient as an elasticity. Firms with a high R&D intensity have more absorptive capacity and search for more advanced knowledge which is not necessarily available at nearby universities (Laursen *et al.*, 2011).

To promote the interactions between firms and universities, regional authorities might offer funding to enforce or stimulate partnerships (e.g. Herstad *et al.*, 2014). This is the case for all regional authorities in Belgium. Hence, the sixth control variable on regional funding (REGFUND) is captured using a binary variable.

Universities are far from a homogeneous group of organizations (Agrawal and Cockburn, 2003). D'Este and Iammarino (2010) state that larger universities attract more research and, therefore, the search pattern of firms in their neighborhood tends to be more localized. However, not all regions are equipped with equally large universities or with universities that are specialized in particular scientific disciplines. Therefore, the second set of control variables focuses on three university characteristics: university research capacity; university research performance; and specialization in terms of applied sciences. First, the size of contract research is dependent on the supply of university research results, and thus on the capability of the university to perform R&D. Contract research, as defined in the introduction of this article, in its broadest definition builds on university knowledge which is the result of past R&D expenditures. Therefore, universities with larger R&D budgets, research infrastructures and research capacities are well placed to attract larger volumes of contract research from firms. Since knowledge is cumulative, a ten year average of R&D expenditures between 2000 and 2009 captures the research capacity of universities. The university research capacity is accounted for in logarithmic terms (LRESCAPA).

Second, empirical studies indicate that firms look for university research results with an eye on the quality of this research (D'Este and Iammarino, 2010; Laursen *et al.*, 2011). Up to date, the debate on the impact of university quality on firm–university interactions remains inconclusive. Geuna and Muscio (2009) find no impact of university quality or academic reputation on the likelihood to engage in interactions with firms. But, based on the Community Innovation Survey, Laursen *et al.* (2011) find positive influences on inter-organizational collaboration according to university quality (measured in terms of university rankings). D'Este and Iammarino (2010) find that geographical distance is curvilinear related with research quality of universities. Academic output is often measured using bibliometric data, but Halffman and Leydesdorff (2010) warn against the possible misleading effects in assessing overall academic performance that is so important in university rankings. Following Auranen and Nieminen (2010), research performance is captured by means of the number of university publications over the period 2004–2009 divided by the respective average of R&D expenditures (RESPERF).

Third, the scientific disciplines in which university research is specialized are posited to play a role in industry–university interaction (Meyer-Krahmer and Schmoch, 1998; D'Este and Patel, 2007; D'Este and Iammarino, 2010; Perkmann *et al.*, 2011; Ramos-Vielba and Fernández-Esquinas, 2012; Muscio *et al.*, 2015). There is no a priori reason to expect that this role is absent when attracting industrial funds through contract research. Following Meyer-Krahmer and Schmoch (1998) and Schartinger *et al.* (2002), scientific disciplines are included in the analysis to account for university specialization. Six disciplines are considered in the Frascati Manual that guides the collection of R&D data at universities (OECD, 2015): natural sciences, engineering and technology, medical sciences, agricultural sciences, social sciences, and humanities. To account for the scientific disciplines with the most potential for commercialization, we follow Perkmann *et al.* (2011) and add up engineering, medical sciences and social sciences (APPLIED). University specialization in these disciplines is, therefore, approximated by the share of R&D budgets in the applied sciences in total R&D expenditure.

The third set of control variables covers the existence of a network of contract research relationships. Firms can have more than one contract relationship with various types of organizations. Bathelt and Henn (2014) promote the inclusion of different constellations of interactive relations to single out the effects of a particular relationship. Roper

Table 1. Descriptive statistics on contract research linkages between firms and domestic universities ($N = 363$)

Variables	Acronym	Mean	SD	Minimum	Maximum
Contract research (in thousand €)	CONTRACT	161.1	383.3	0.2	4816.4
Distance (in km)	DIST	60.1	43.6	0.1	184
Location in the same region	REGION	0.90	0.30	0	1
Firm characteristics					
Firm size (employment in full-time equivalent)	SIZE	479.9	884.8	1	6027
Firm age (years)	AGE	31.3	27.7	1	125
Foreign controlled firm	GROUP	0.31	0.46	0	1
Sector—Knowledge intensive services	SECT-KI	0.12	0.32	0	1
Sector—science based	SECT-SB	0.19	0.39	0	1
Firm R&D intensity	RDINT	0.13	0.22	0.00	0.99
Firm benefits from regional funding	REGFUND	0.64	0.48	0	1
University characteristics					
Average R&D expenditure at domestic universities (in mio €)	RESCAPA	208.4	82.1	12.4	291
Performance (publications per million R&D expenditures at university)	RESPERF	13.9	6.5	4.6	81.5
Share of R&D expenditure in engineering, medical and social sciences (in % of total R&D expenditures)	APPLIED	0.59	0.12	0	1
Network characteristics					
Number of other contracts with non-profit organizations	NNPO	0.40	0.61	0	2
Number of other contracts with domestic universities	NDUNI	0.58	0.69	0	2
Number of other contracts with foreign universities	NFUNI	0.08	0.29	0	2

et al. (2017) stress that the extent of network activity impacts innovative activity. Hence, acquiring knowledge through contract research co-depends on alternative network relations. Following Drejer and Østergaard (2017), even in the case of a firm and a university involved in contract research, the same firm can frequent other partners from private non-profit organizations, public, and collective research centers (NNPO), other domestic universities including other university departments at the same university (NDUNI), and foreign universities (NFUNI). Finally, an additional control variable is introduced for the three surveys used to construct the database.

In summary, this article aims to explain the size of contract research commissioned by a firm (i), expressed in terms of natural logarithms to correct for its skewed distribution (LCONTRACT), by means of the following empirical model:

$$\mathrm{LCONTRACT}_i = b_1\mathrm{LDIST}_i + b_2(\mathrm{LDIST}_i)^2 + b_3\mathrm{REGION}_i + b_u U_i + b_v V_i + b_w W_i + b_z Z_i + e_i$$

LDIST is the natural logarithm of the distance between the contracting firm and the university. REGION is a dummy variable indicating co-location in the same region of the firm and the university contracted to. The vector U_i stands for the respective surveys; the vector V_i captures the control variables at firm level (LSIZE, AGE, GROUP, SECT-KI, SECT-SB, LRDINT, and REGFUND); and the vector W_i captures the control variables covering the university characteristics (LRESCAPA, RESPERF, and APPLIED). As a firm may have up to three (most important) contracts to non-profit organizations, and each of them is considered separately in the analysis, the vector Z_i controls for the other network relationships (NNPO, NDUNI, and NFUNI). The symbol ε_i is the error term. Table 1 gives a more detailed overview of all these variables for the 363 contract research linkages by 287 firms with domestic universities.

The average size of a contract is 161.1 k€. The distances between firms and universities vary between 100 m and 184 km, implying an average of 60.1 km (median of 51 km). About 90% of the contracts are between firms and universities in the same region. Firms having contract research are rather large (479.9 full-time equivalents) and mature (an average of 31.3 years). About one out of three firms belongs to an international group (31%) and is high R&D intensive (13%). Almost two-thirds of the firms (64%) benefit from regional funding. The university characteristics show that universities have an average R&D expenditure of 208.4 million €. The intensity of publications yields an idea of the research performance and reveals a large heterogeneity between universities in this respect as the number

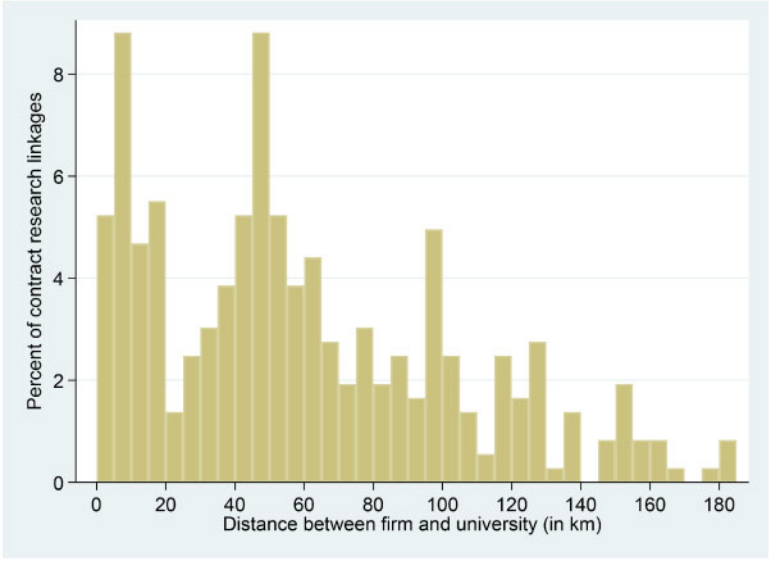

Figure 2. Geographical distance between firms and universities with contract research linkages.

varies between 4.6 and 81.5 publications per million R&D expenditures (average 13.9). The majority of R&D expenditures of universities are devoted to the applied sciences (59%).

The analysis on the size of contract research between firms and universities in the context of a small country such as Belgium implies that geographical distance is limited and that a large majority of the contract research agreements in the analysis are between partners within a rather short distance, even a "commuting distance." Although, it should be noted that Belgium is characterized by distinct problems in terms of congestion, making commuting notoriously difficult. The fact of limited distances has implications for the analysis and for the interpretation of results, since our findings for domestic contracts will refer to a particular distribution of distances, the majority of which are rather short, compared with similar studies in the field. In other words, referring to large distances in the interactions with domestic universities would not often qualify as such in many other countries (particularly in larger countries). Given the centrality of geographical distance in the article, Figure 2 provides further details on the distribution of distances corresponding to the sample of R&D contracts. The geographical distance of the 363 contract linkages with universities is divided in tranches of 5 km. From the figure it follows that the distance is not equally distributed over space: 24.2% of the contract linkages is located within 20 km; 24.8% between 20 and 50 km; and 17.6% are located further than 100 km from the university.

4. Analytical results

Table 2 presents the empirical results on the relation of geographical distance and regional co-location on the size of contract research between firms and domestic universities. Five different models are tested.

Model 1 is the base model and checks for firm, university, and network control variables, together with a potential survey effect. The size of contract research significantly increases with firm size (LSIZE): having more resources, larger firms obviously spend, on average, more on contract research with universities than smaller firms. For firm age (AGE) there is no significant relationship, meaning that it is irrelevant whether firms contracting out research to universities are young or old. It could be expected that firms belonging to a foreign group (GROUP) might tend to spend more at universities tapping into the local knowledge base (Narula, 2014), but this is not corroborated by the estimated coefficient in Model 1. When looking at the effect of sector activity, the estimated coefficients should be interpreted in relation to all other sectors in the economy (which is the reference category). Firms active in the knowledge intensive services sector (SECT-KI), such as communication services, are no different in the size of contract research spent at universities than their counterparts in other sectors. Firms active in the science-based sector (SECT-SB), such

Table 2. Determinants of the size of firms' contract research with domestic universities

	Model 1—base model	Model 2—geographical distance (linear)	Model 3—geographical distance (non-linear)	Model 4—regional co-location	Model 5—geographical distance and regional co-location
Constant	–0.999 (2.252)	–0.989 (2.254)	–0.641 (2.145)	–1.018 (2.189)	–0.641 (2.086)
Survey-2008	0.116 (0.207)	0.116 (0.207)	0.145 (0.207)	0.081 (0.204)	0.111 (0.203)
Survey-2010	–0.041 (0.219)	–0.041 (0.219)	–0.019 (0.217)	–0.069 (0.216)	–0.048 (0.214)
LSIZE	0.460 (0.059)***	0.460 (0.059)***	0.465 (0.058)***	0.460 (0.058)***	0.464 (0.057)***
AGE	0.003 (0.003)	0.003 (0.003)	0.002 (0.003)	0.003 (0.003)	0.003 (0.003)
GROUP	0.006 (0.191)	0.007 (0.191)	0.053 (0.192)	0.009 (0.188)	0.056 (0.189)
SECT-KI	0.285 (0.343)	0.287 (0.343)	0.239 (0.345)	0.281 (0.345)	0.245 (0.348)
SECT-SB	0.561 (0.258)*	0.560 (0.259)*	0.553 (0.259)*	0.575 (0.252)*	0.564 (0.253)*
LRDINT	0.318 (0.076)***	0.319 (0.078)***	0.326 (0.078)***	0.313 (0.076)***	0.324 (0.077)***
REGFUND	0.601 (0.207)**	0.600 (0.209)**	0.572 (0.209)**	0.596 (0.209)**	0.564 (0.211)**
LRESCAPA	0.131 (0.117)	0.130 (0.118)	0.143 (0.114)	0.098 (0.115)	0.105 (0.112)
RESPERF	0.023 (0.011)*	0.023 (0.011)*	0.023 (0.011)*	0.025 (0.012)*	0.025 (0.012)*
APPLIED	0.455 (0.574)	0.456 (0.575)	0.326 (0.572)	0.515 (0.585)	0.396 (0.583)
NNPO	–0.337 (0.131)*	–0.336 (0.132)*	–0.336 (0.131)*	–0.346 (0.131)**	–0.345 (0.130)**
NDUNI	0.057 (0.144)	0.055 (0.146)	0.049 (0.145)	0.097 (0.142)	0.083 (0.144)
NFUNI	–0.153 (0.334)	–0.155 (0.337)	–0.167 (0.341)	–0.141 (0.338)	–0.163 (0.345)
LDIST		0.005 (0.069)	–0.443 (0.154)**		–0.401 (0.157)*
LDISTsq			0.077 (0.026)**		0.073 (0.026)**
REGION				0.621 (0.229)**	0.611 (0.234)**
F-statistic (*P*-value)	12.25 (0.000)***	11.46 (0.000)***	11.62 (0.000)**	12.60 (0.000)***	11.85 (0.000)***
R^2	0.378	0.378	0.387	0.390	0.398
Adjusted R^2	0.351	0.350	0.357	0.362	0.367
Observations	363	363	363	363	363

Notes: The dependent variable is the amount of contract research by a firm to a university (log transformed). Reference categories are used to avoid singularity: Survey-2008 and -2010 use Survey-2006; SECT-KI and SECT-SB use all other sector activities. Robust standard errors in parentheses control for possible cluster of reporting units belonging to the same firm. The symbols *, ** and *** stand for 5%, 1%, and 0.1% level of significance, respectively. The variance inflation factors are well below three. To avoid multicollinearity of the squared term we have used the following formula $x^2 = (x - x_{average})^2$, as in Broekel and Boschma (2012).

as pharmaceuticals, spend significantly more on university contract research than firms in other sectors. The nature of the knowledge involved could explain this (Olmos-Peñuela *et al.*, 2014). A particular control variable is the R&D intensity (LRDINT) of the firm that has contract research with universities. R&D intensity is often considered a proxy of the absorptive capacity of the firm, meaning that the firm invests in its own knowledge base to incorporate the acquired research results developed at universities (Geuna and Muscio, 2009; Spithoven and Teirlinck, 2015). As expected, there is a significant positive relation between this variable and the size of contract research to universities. Model 1 further controls for the regional funding (REGFUND) of firms' R&D expenditure. There is no information in the database on the nature of this regional funding, whether it is conditional on having contract research or using another channel of external knowledge, but each of the regions in Belgium has at least some policy measures directed to stimulating various firm–university relationships. When a firm receives public regional funding, the size of its contract research is significantly higher than without access to such funding.

Model 1 also introduces three university characteristics. Higher research capacities (LRESCAPA) of universities in terms of (the log of) R&D expenditure do not seem to be related to the size of contract research. Therefore, universities having more research infrastructure, more R&D personnel, and higher R&D expenditures, do not attract larger-sized contract research as posited by D'Este and Iammarino (2010). However, firms spend larger volumes on contract research with universities that demonstrate better research performance in terms of publications per million of R&D expenditure (RESPERF). Finally, higher shares of R&D expenditure in applied sciences (APPLIED), such as engineering, medical sciences, and social sciences are not associated with larger-sized contract research. This corroborates the ideas expressed in Olmos-Peñuela *et al.* (2014).

The next set of control variables in Model 1 looks at the relevance of firms' other network relations (Gulbrandsen and Smeby, 2005). These include relations with other non-profit organizations (NNPO), and/or other domestic universities or departments from the same university (NDUNI), and/or foreign universities (NFUNI). Model 1 shows that when a firm has contract research with non-university public research organizations, the size of the contract research to the university is significantly lower. One reason for this may be that the knowledge or research content is more development oriented and less related to core research activities undertaken at most universities in Belgium (Teirlinck and Spithoven, 2012). Additional network relations involving contract research with other universities, either domestic or foreign, have no impact on the amount of contract research to a university. All these variables are robust in the base model and in the next four models (Models 2–5) adding variables of interest in terms of geographical distance and regional co-location.

Model 2 adds the geographical distance in its linear form (LDIST). Apparently there is no association between the geographical distance and the size of contract research. Hence, the established negative impact of distance on university–firm relations is not corroborated when the size of contract research between firms and universities is concerned. This confirms the findings of Schartinger *et al.* (2002) and Uyarra (2010) that not all distant university–industry linkages demonstrate lower budgets involved in knowledge transfer.

Model 3 enters the non-linear distance (LDIST and LDISTsq), which becomes highly significant in the context of the size of contract research. The estimated coefficients demonstrate a U-shape indicating that sizes of contract research are higher when firms are located more closely to universities and, at the same time, also higher for firms located farther away from universities. The ideas of technology clustering (Bathelt *et al.*, 2004), the anchoring role of universities (Roper *et al.*, 2017), and the existence of (domestic) knowledge pipelines (Broström, 2010; Berchicci *et al.*, 2016) or technology coupling (Corradini and De Propris, 2017), are corroborated in terms of size of contract research. Hence, the non-linear relation found between the size of contract research and geographical distance supports the acceptance of Hypothesis 1. The minimum of the quadratic function in Model 3 lies at 17.8 km at which point the size of contract research from firms to universities is, on average, the lowest. Within this distance we find 21.5% of all contractual relationships between firms and universities. Universities located nearer to firms collect, on average, higher sizes of contract value and may be part of a specific technological cluster or have a trust relationship between individual researchers of firms and local universities. Universities located farther away also show higher sizes of contract research, indicating the existence of knowledge pipelines (Bathelt *et al.*, 2004) or pointing to the need for more distant knowledge to complement existing resources (Spithoven and Teirlinck, 2015). These results confirm the existence of hub-and-spoke structures (Broekel and Boschma, 2012) in terms of the size of contract research.

Regional co-location captures the sense of belonging to the same environment with the same norms and values generating mutual trust (Cooke *et al.*, 1997; Gordon and McCann, 2000). Keeping the other findings stable, the strong significance of regional co-location in Model 4 indicates that firms and universities that are co-located tend to have significant larger-sized contract research agreements between them. Hypothesis 2 must therefore be accepted.

Model 5 builds on the previous model and shows that regional co-location is still positively associated with the size of contract research when the non-linear conception of distance is included, showing the robustness of the results in Models 3 and 4. Model 5 also shows that the relationship between geographical distance and the size of contract research remains U-shaped even when controlling for regional co-location. In Model 5, the minimum of the quadratic function is 15.6 km, covering 20.1% of the contracts in this spatial reach.

A curvilinear relationship comes in different forms, as its shape might be monotonously declining (L-shaped), increasing (J-shaped) or more balanced (U-shaped). Figure 3 is based on Model 5 of Table 2, and zooms in on this relationship between geographical distance and the size of research contracts from firms to universities. The U-shape is clearly largely balanced indicating that short and large distances are more or less equally (corroborated by the absence of significance of the linear relation, LDIST) related to the size of contract research between firms and universities.

5. Conclusions

This article focused on the spatial dimension—in terms of geographical distance between, and regional co-location of, firm and university—and the size of firms' research contracts to universities. The size of contract research has not been studied intensively, even though contract research is cited as an important channel in firm–university interactions (Schartinger *et al.*, 2002).

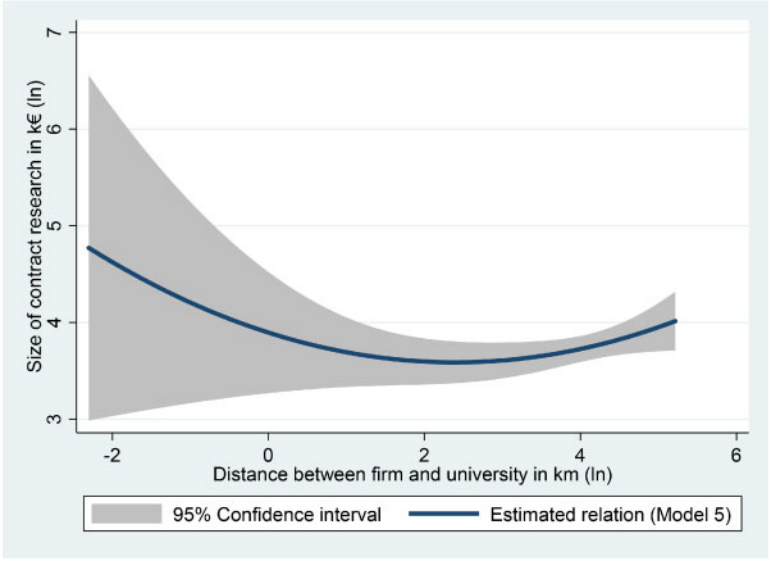

Figure 3. Estimated relation between the size of contract research and geographical distance.

The empirical analysis is based on a unique database created through micro-linking the OECD R&D survey for firms with the one for universities. This allowed obtaining detailed information on the size of contract research by firms to universities and the spatial dimensions of this relationship with the university. The focus was on contract research with domestic universities in Belgium, a small and densely populated country characterized by relatively limited geographical distances between research actors.

It has been demonstrated that the size of the firm to university contract research is higher when a firm is close to the university, reaches a minimum at around 15.6–17.8 km, and then increases again with distance. This U-shape is balanced in the sense that the relation of small and of large distances on the size of contract research is similar. It has also been demonstrated that regionally co-located firms and universities hold significantly larger-sized contract research between them.

These findings enrich the literature on university–industry interaction through its focus on the rarely discussed channel of contract research. Because there are no firm-level data available on the size of the research contract, a definite shortcoming in most existing literature is that the amounts involved cannot be discussed. Notable exceptions are Perkmann *et al.* (2011) and Bodas Freitas *et al.* (2014), who do not focus on the relation with distance. By linking two databases on firms and universities, respectively, this analysis is no longer limited to analyzing the probability of university–industry linkages by the presence or absence of contract research. This article draws on the size of the research contract itself, thereby complementing existing analyses. The findings provide new insights in particular with respect to the size of contract research and the on-going ambiguous role of geographical distance (Broström, 2010) in three ways.

First, the results deepen the understanding of firms buying university knowledge at different spatial scales, acknowledging the spatial specificity of knowledge (Roper *et al.*, 2017). On the one hand, short distances between firms and universities are associated with higher sizes of contract research indicating the existence of technology clusters where universities that are located nearby are part of (e.g. Laursen *et al.*, 2011). These clusters are characterized by a high degree of mutual trust and social capital (Breschi and Lissoni, 2001), enhanced (tacit) knowledge transfer (Fitjar and Gjelsvik, 2018), and/or higher efficiency in knowledge transfer (Holcomb and Hitt, 2007). On the other hand, the desired knowledge might be located at distant universities, and based on the resource-based view firms search complementary knowledge and technical sources wherever available to them (Spithoven and Teirlinck, 2015). Laursen *et al.* (2011) posit that geographical distance is of lesser importance than research quality. Complementary knowledge, especially in case of radical new knowledge, is more often sought at more distant contract research partners, a conclusion that is also drawn in recent academic literature (e.g. Berchicci *et al.*, 2016).

Second, our findings further extend the debate on the effects of regional co-location of firms and universities. Being co-located in the same region not only displays a positive association with the likelihood of university–industry interactions (Caniëls and van den Bosch, 2011), it also positively influences the size of contract research in these interactions. This confirms the difficulties to reproduce (Asheim and Isaksen, 2002) the ease co-location offers for tapping into knowledge repositories, expertise and skills (Bathelt *et al.*, 2004; Malecki, 2010).

Third, in addition to the role of geographical distance and regional co-location, insight is provided with respect to the relation of firm, university, and network characteristics on the size of contract research. Firm size, being active in the science-based industry, firm R&D intensity, and obtaining regional research funding are confirmed as positive determinants for the size of contract research (Geuna and Muscio, 2009; Olmos-Peñuela *et al.*, 2014). Neither can universities be considered as a homogenous group since their research performance in terms of publication intensity (Auranen and Nieminen, 2010) positively influences the size of contract research attracted (Laursen *et al.*, 2011). Contract research with non-profit organizations negatively influences the size of industry–university contract research. This might be related to firms making considered choices in terms of the public partner (network) they contract research to (Bathelt and Henn, 2014; Roper *et al.*, 2017), and/or an overall research content that is more development oriented and further away from the core research activities undertaken at most universities in Belgium (Teirlinck and Spithoven, 2012).

Three policy implications arise from this article. First, with respect to geographical distance, policy makers should be aware that an exclusive focus on local clusters is potentially at odds with firms' knowledge requirements, which might reside at nearby or at distant located universities. Second, the analyses indicate that firms are more likely to spend higher amounts of contract research on universities if firms have relatively high absorptive capacity in terms of R&D intensities. Policies directed at promoting knowledge flows between firms and university can do so by reinforcing R&D intensities of firms through various policy measures. Stimulating these firm-level aspects could be considered an option by policy-makers responsible for the design and implementation of policy instruments aimed at reinforcing university–industry linkages. Third, policy makers are invited to strengthen the performance of academic research at universities. Higher publication intensity facilitates access to codified quality research which strengthens the reputation of universities and, through that, may open up new networks at (distant) universities.

This study has some limitations which serve as an agenda for future research efforts. First, the generalizability of our findings should be tested in other countries with regionalized science policy and a limited knowledge base due to their small scale and to countries confronted with larger distances between research actors. Up to date, the limited empirical evidence stems from different types of linkages such as patents (Petruzzelli, 2011) or collaboration (Hewitt-Dundas, 2013; Berchicci *et al.*, 2016). Second, firms in small open economies might easily have linkages with foreign universities, especially as the globalization of research increases. The dataset used in this article contains some information on this, but the number of observations was too small to offer a representative picture. Finally, in terms of measuring contract research, there is a need for more information with respect to the duration and the exact content of the research that has been commissioned in the contract.

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Appendix

Table A1. Sample of contracts ($N = 363$) compared with population ($N = 589$ including missing values)

Acronym	Variable	Observations	Population Mean	Standard error	Sample Mean	Standard error	Difference of means (significance)
CONTRACT^{+}	Contract research (thousand €)	450	165.7	18.0	161.1	20.1	−4.62
DIST^{+}	Distance (km)	581	58.0	1.74	60.1	2.29	2.07
REGION$^{\#}$	Location in the same region	589	0.76	0.02	0.90	0.02	0.14**
Firm characteristics							
SIZE^{+}	Firm size (employment)	583	513.3	58.1	479.9	46.4	−33.44
AGE^{+}	Firm age	589	29.3	1.18	31.3	1.45	1.85
GROUP$^{\#}$	Firm belongs to a foreign controlled group	589	0.32	0.02	0.31	0.02	−0.01
SECT-KI$^{\#}$	Sector -Knowledge intensive services	589	0.11	0.01	0.12	0.02	0.01
SECT-SB$^{\#}$	Sector—science based	589	0.24	0.02	0.19	0.02	−0.05*
RDINT^{+}	R&D intensity	509	0.12	0.01	0.13	0.01	0.00
REGFUND$^{\#}$	Funding by regional government for R&D by the firm	589	0.61	0.02	0.64	0.03	0.03
University characteristics							
RESCAPA^{+}	Average R&D expenditure at universities (mio €)	567	193.0	3.39	208.4	4.31	15.40
RESPERF^{+}	Performance (publications per million R&D expenditures at university)	564	16.62	1.92	13.88	0.34	−2.73**
APPLIED^{+}	Share of R&D expenditure in applied sciences (in % of total R&D expenditures)	586	0.61	0.01	0.59	0.01	−0.02 **
Network characteristics							
NNPO^{+}	Number of other contracts with non-profit organizations	589	0.35	0.02	0.40	0.03	0.05
NDUNI^{+}	Number of other contracts with domestic universities	589	0.66	0.03	0.58	0.03	−0.07
NFUNI^{+}	Number of other contracts with foreign universities	589	0.07	0.01	0.08	0.02	0.01

Notes: the symbol + stands for t-test, and the symbol # stands for Pr-test, The symbols * and ** stand for 10% and 0.1% level of significance.