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(Article begins on next page)

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Academic engagement with industry: the role of research quality and experience

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Abstract
This work explores the role of university department characteristics in academic engagement with industry. In particular, we investigate the role played by research quality and previous experience in academic engagement across different scientific disciplines. We test our hypotheses on a dataset of public sponsored university-industry partnerships in the United Kingdom, combined with data from the UK Research Assessment Exercises 2001 and 2008. Our analysis reveals a negative link between academic quality and the level of engagement with industry for departments in the basic sciences and a positive relationship for departments in the applied sciences. Our results further show that the role of research quality for academic engagement strictly depends on the level of the department's previous experience in university-industry partnerships, notably in the basic sciences, where experience acts as a moderating factor. The findings of this work are highly relevant for policy makers and university managers and contribute to the innovation literature focused on the investigation of the determinants of valuable knowledge transfer practices in academia.

Keywords Academic engagement · Academic quality · Experience · University-industry collaboration

JEL Classification I23 · O30

1 Introduction

Universities are key agents of economic and social progress. Their mission has gradually been extended to interactions with industry, and with society more generally, beyond the traditional goals of teaching and research (e.g. Bercovitz & Feldman, 2006; Archibugi & Filippetti, 2018; Giuri et al., 2019). The role of universities so conceived has attracted

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considerable attention from scholars and policy-makers (e.g. Hsu et al., 2015; Trune & Goslin, 1998; Kochenkova et al., 2016). As a matter of fact, university engagement in knowledge transfer and dissemination of research results ("third mission" activities) is investigated by various streams of the academic literature, including economics of innovation, economic geography, geography of innovation, and economics of science. University engagement activities take various forms, including employment channels, intellectual property rights (IPRs) related interactions, research collaboration, and informal direct/indirect contacts (e.g. Geuna & Rossi, 2013; Rossi & Rosli, 2013). However, whilst university IPR-related activities and academic entrepreneurship have attracted major attention both within the academic literature and the policy community (Phan & Siegel, 2006; Rothaermel et al., 2007; O'Shea et al., 2008), other types of university–industry (U–I) interaction have become more prevalent (Perkmann et al., 2013). This is notably the case of research partnerships, which refer to a specific typology of university interaction with industry entailing firms and university joint research and financial effort within a specific collaborative project (e.g. D'Este & Iammarino, 2010; Scandura, 2016).

Despite the well known benefits accruing from U–I interaction for both parties as well as for the society as a whole, linkages are often hampered by differences in the research missions of university and industry (Bodas-Freitas & Verspagen, 2017; Dasgupta & David, 1994). In particular, due to different research-related incentive structures in academia and industry, the diverse research missions and motivations for interaction can be hard to reconcile in a collaborative framework. Yet, the innovation literature has underlined that the alignment between motivations for collaboration is fundamental for the successful set up of a collaboration (Foray & Steinmuller, 2003; Ankrah et al., 2013). The trade-off between motivations for collaboration is particularly important when the research pursued inside academia is aligned to basic research while the research and development activities (R&D) inside companies mostly involve applied research (Bodas-Freitas & Verspagen, 2017).

In the attempt to understand what influences the realisation of U–I interactions and their success, the innovation literature has scrutinized in depth the determinants of U–I partnerships (e.g. Schartinger et al., 2002; Fontana et al., 2006; D'Este & Iammarino, 2010; D'Este et al., 2013). However, while the role of individual-level factors is rather well explored, the empirical evidence is scant about the context in which U–I partnerships occur, mostly with respect to the characteristics of the university departments involved (Perkmann et al., 2013). Yet, the department routines, together with the university culture and policies, are likely to have the largest influence on researchers' behaviour, including their attitudes towards U–I interactions (D'Este & Patel, 2007). Interestingly, whilst the relevance of the research standing of academic departments has been investigated (e.g. Mansfield, 1995, 1997; Mansfield & Lee, 1996; Tornquist & Kallsen, 1994), its joint effect with other contextual factors on U–I interactions remains mostly unexplored. In particular, it is beyond doubt that the patterns in U–I partnerships depend on the scientific origin of academic departments and researchers (e.g. Bekkers & Bodas Freitas, 2008; D'Este & Iammarino, 2010; Mansfield & Lee, 1996), but the empirical evidence is still scarce about the joint effect of research quality and scientific disciplines. A few contributions point to differences between hard sciences and humanities as well as between applied and basic sciences, suggesting that the effects of research quality and scientific disciplines on U–I partnerships may be interdependent (D'Este & Iammarino, 2010; Olmos-Peñuela et al., 2014). Similarly, while cumulated experience in academic engagement has been shown to be a predictor of future engagement, its influence on the link between research quality and U–I partnerships is an underexplored issue in the literature (Boardman & Ponomariov, 2009; Bozeman & Gaughan, 2007). In particular, whether the influence of research quality holds when academia cumulates experience in U–I interactions remains an open question. In this paper, we intend to fill these gaps and extend the existing literature in various directions.

Firstly, we investigate the role played by university department research quality for the level of academic engagement in U–I partnerships, by distinguishing between departments in basic and applied hard sciences. We test the hypotheses that academic quality is negatively related to U–I partnerships in basic sciences departments, and positively related to it in applied sciences departments. Our hypotheses build on the argument that the successful realisation of a collaboration depends on the alignment of research motivations and expectations of the partners (Foray & Steinmuller, 2003; Ankrah et al., 2013). We focus on the analysis from the university side and argue that the alignment process plays out differently across scientific disciplines and quality levels, due to the diverse degree of resource availability and institutional norms and values inside university departments. Given the different motivations driving basic and applied sciences departments toward academic engagement, we posit that researchers in basic sciences departments of high quality are pushed away from U–I interactions, whilst their peers in top applied sciences departments are highly engaged. Secondly, we focus on department-level cumulated experience in U–I partnerships as a joint determinant of academic engagement together with research quality. We postulate that department past experience weakens the negative relationship between academic quality and engagement in the basic sciences, while it amplifies the positive link in the applied disciplines. We base our hypotheses on the argument that department experience in academic engagement influences the capability to fruitfully establish and maintain connections with firms and that the extent of such influence changes across scientific disciplines.

To address these issues, we carry out regression analyses on a dataset of U–I partnerships funded by the UK Engineering and Physical Sciences Research Council (EPSRC), combined with data on academic institutions from the UK Research Assessment Exercises (RAE) developed by the UK Higher Education Funding Councils. In the empirical analysis, we account for academic departments' engagement in U–I partnerships by considering the level of financial resources involved. In doing so, we overcome one of the limitations in extant research, namely the lack of information on the amount of financial flows at stake (Perkmann et al., 2011). Yet, income flows that university departments receive for their knowledge transfer activities may reflect the value placed by external partners on academic knowledge, thus providing a measure of the economic value created through knowledge transfer (Rossi & Rosli, 2013).

The paper is organised as follows: we review the relevant literature and develop our empirical hypotheses in Sect. 2; in Sect. 3 we illustrate data sources, variables and methodology; the empirical results along with robustness checks are presented in Sect. 4; finally, we discuss our findings and offer some concluding remarks in Sect. 5.

2 Literature and hypotheses development

2.1 Motivations for U–I collaboration

Universities carry out a wide range of collaborative initiatives, often labelled *academic engagement*. As defined by Perkmann et al. (2013), this refers to inter-organisational collaboration that links universities with other organisations, especially firms, and includes both formal activities (e.g. collaborative research, contract research and consulting) and informal activities such as networking with practitioners. Although there is extensive research on university IPRs activity and academic entrepreneurship, it is widely recognized that other forms of academic engagement are more pervasive (Perkmann et al., 2013). In this respect, U–I collaborative research partnerships stand out: these are a specific channel of inter-organisational knowledge flows and potential spillovers from (and to) academic research, aimed at carrying out R&D projects, mainly involving pre-competitive and basic research and often subsidized with public funding (D'Este & Fontana, 2007; D'Este et al., 2013; OECD, 1998, 2002; Scandura, 2016). U–I research partnerships represent one of the most frequent policy instruments put in place by policy-makers to incentivize U–I knowledge transfer and foster pre-competitive research (Fisher et al., 2009).

The successful set up of a collaboration depends on the alignment of research motivations and expectations of the partners (Foray & Steinmuller, 2003; Ankrah et al., 2013). Bodas-Freitas and Verspagen (2017) refer to it as the integration of the objectives of partners belonging to different technological and institutional environments into joint projects that may benefit both parties. The alignment of motivations is particularly important when the partners are driven by different incentives to collaborate, as typically in collaborations between university and companies. Indeed, the different incentive frameworks in academia and industry are often cited as a constraining factor of U–I interactions and their outcome (Dasgupta & David, 1994; Rosenberg & Nelson, 1994).

Academic scientists collaborate with companies to search for practical applications of their research results, to advance and widen their research agendas, to get funding for their research, for graduate students and for purchasing equipment, and to increase the chances for future collaboration opportunities (D'Este & Perkmann, 2011; Lam, 2011; Lee, 1996, 2000; Lee and Bozeman, 2005; Perkmann & Walsh, 2009). Firms are motivated to collaborate with universities to access and develop interdisciplinary scientific capabilities to solve complex industry problems, to get support for the product development phase of their R&D activities, to access public funding, to pursue exploratory research to generate new ideas for new products, technologies and markets as well as to get access to highly skilled labour force, most notably qualified engineers (Meyer-Krahmer & Schmoch, 1998; Lee, 1996, 2000; Feller et al., 2002; Carayol, 2003; Lam, 2005; Balconi & Laboranti, 2006; Arza, 2010; Subramanian et al., 2013).

Some of these motivations are expected to easily converge in a collaborative framework because complementary to each other. For instance, academic scientists' search for industrial application of their inventions can match firms' product development objectives (Bodas-Freitas & Verspagen, 2017). However, motivations may also conflict, hence preventing full accordance between university and industry.[1] A typical example of conflict is the clash between the university objective of opening up new research paths and firms' product development goals: while the exploration of new research lines is aligned to basic research, product development involves applied research building on the results of basic research (Bodas-Freitas & Verspagen, 2017).

Both the theoretical and empirical innovation literature helps understanding the difference between basic/fundamental research and applied/practical research, and how it relates to university and industry diverse motives for collaborating. Investigating the advantages

[1] Extant research shows that diverse motivations to U–I collaboration are not always nor necessarily in conflict (Ankrah et al., 2013; Lee, 2000). When in contrast, industry and university motivations can be reconciled into a collaborative project with well-defined technological objectives and organisation, eventually relying on different institutions (e.g. technology transfer offices) (Lam, 2011; Subramanian et al., 2013).

and disadvantages of academic and private-sector research, Aghion et al. (2008) argue that the critical trade-off between academia and industry is one of creative control versus focus. Because of its commitment to keep creative control in the hands of scientists, academia is indispensable for early stage basic research aimed at fostering new research lines; at the same time, the private sector's focus on higher payoff activities makes it more useful for later-stage applied research, aimed at producing profitable innovations and introducing them to the market. The divergence in incentive structures—but also norms, language and purposes—between the two worlds is likely to be particularly strong when the academic partner is most oriented towards upstream blue-sky research as compared to research closer to the context of application (Dasgupta & David, 1994). Relatedly, the characteristics of the knowledge stemming from research activities play a key role in shaping the link between academia and industry (Meyer-Krahmer & Schmoch, 1998). The output of basic research is characterised by low marketability and applicability as the knowledge generated mostly originates from blue-sky research that is far from industrial application: such knowledge is most often at the frontier, highly tacit, hence less codifiable by those who do not command the field of investigation (Aghion et al., 2008; Dasgupta & David, 1994). Companies are generally only scarcely interested in this typology of research because of its high riskiness and intrinsic low appropriability: given firms' profit maximisation objectives, they will be less interested in new knowledge that is likely to be less marketable (Aghion et al., 2008). On the contrary, the output of applied research activities is by definition closer to the business community (Meyer-Khramer & Schmoch, 1998). The artefacts in applied sciences are tangible and thus open to direct, experience-based manipulation, as opposed to the products of basic sciences. Therefore, applied research pursued in fields such as engineering is highly applicable for industrial purposes as it generates knowledge with high technical and market related content (Meyer-Khramer & Schmoch, 1998).

The orientation of academic researchers towards basic or applied research is naturally related to the scientific discipline they are affiliated to. Substantial disciplinary effects stand out in the extant literature on academic engagement, including the specific case of research partnerships (e.g. Schartinger et al., 2002; Bekkers & Bodas-Freitas, 2008; D'Este & Iammarino, 2010). Academic affiliation to a scientific discipline shapes the norms relevant for researchers as these are the rules of conduct that prevail within the so-called "invisible colleges" in which academic scientists operate (Crane, 1972). The disciplinary origin of an academic department has been shown to be an important factor affecting the typology and the extent of engagement with industry (Bekkers & Bodas-Freitas, 2008; Martinelli et al., 2008). The literature suggests that collaboration and engagement in entrepreneurial activities are more likely to happen in applied fields of research as compared to less applied domains (Perkmann et al., 2013). For instance, informal contacts, collaborative and contract research, patents and licensing are important channels of knowledge transfer for engineering-related departments, while researchers oriented at basic research tend to value much less patents and licensing. Conversely, academic departments of economics and other social sciences tend to transfer knowledge through publication, personal contacts, labour mobility and specific organised activities (Bekkers & Bodas-Freitas, 2008). In the medical sciences, clinical researchers are more likely to interact with firms with respect to their non-clinical peers, but the latter are more engaged in commercialisation activities (Louis et al., 2001).

Against the complex process of convergence between university and industry's research missions across different scientific disciplines, public grants may create incentives for specific motivations for U–I collaboration. Participation to public sponsored U–I collaborations may not be critical to firms' competitive position, but it may provide both university and industry an opportunity to collaborate in a context where opportunistic behaviour does not represent a severe problem (Sakakibara, 1997; Tripsas et al., 1995). In particular, public funding for U–I collaboration provides incentives for trust building among partners, and influences the extent of new product/process development and the ability to gain knowledge and spillovers (Nishimura & Okamuro, 2016; Okamuro & Nishimura, 2015). Therefore, the literature suggests that publicly funded U–I research collaborations are expected to favour the coexistence of diverse motivations: i.e., university motivations to access research funds and to build and nurture their research networks for future collaboration, and industry motivations to complement their research agenda and source additional funding (Balconi & Laboranti, 2006; D'Este & Perkmann, 2011; Lee, 1996, 2000).

2.2 The role of research quality for academic engagement across basic and applied sciences

Innovation scholars have devoted a great deal of attention to the role of research quality among the many determinants of U–I interactions. In their seminal contributions, Mansfield (1995, 1997) and Mansfield and Lee (1996) show that academic research excellence is a driver for companies that are interested in carrying out joint research activities with universities, thus seeking proper support for the technology issues faced during the innovation process. In the same vein, Tornquist and Kallsen (1994) show that the research output of high quality universities has a greater potential for industrial application, hence meeting the research needs of innovative companies. Similarly, a number of works show that the most successful academics are often those who engage the most in joint research with industry (e.g. Gulbrandsen & Smeby, 2005; Bekkers & Bodas-Freitas, 2008; Haeussler & Colyvas, 2011; Crescenzi et al., 2017).

While the literature seems to indicate that research quality is largely positively related to academic engagement, the net effect of academic excellence on the participation in U–I interaction has also been found to be negative or non-existent. Mansfield and Lee (1996) find that less prestigious universities generate findings that are considered highly important by firms, hence underscoring that second-tier universities do substantially contribute to industrial innovation. Laursen et al. (2011) also find that low quality universities are best placed to collaborate with local R&D intensive firms. Comparing university and individual levels of analysis, Ponomariov (2008) shows that the role of academic quality is generally positive at the institutional level, while the higher the average quality of an institution, the lower the propensity of individual scientists to interact with the private sector. According to D'Este et al. (2013), the pursuit of high academic excellence is neither impaired nor enhanced by business engagement across UK academic departments.

The literature thus shows that academic standing affects the extent and typology of U–I interactions, albeit not always reaching the same conclusion on the direction and size of such effect. As postulated by Perkmann et al. (2011), uncovering discipline-specific differences related to academic research quality might explain variations in existing empirical evidence and contribute to the academic debate on the topic. The reason is that the different ways of pursuing academic research across disciplines determine the potential benefits that researchers derive from collaborating with industry (Perkmann et al., 2011; Filippetti & Savona, 2017), hence influencing the motivations for collaborating and, as a consequence, the extent and the characteristics of collaborations. However, only few contributions investigated the specific link between the quality of scientific research and academic engagement across scientific disciplines. D'Este and Patel

(2007) show that scientists from poorly rated departments seem to engage in a wider range of interactions with industry, but this is only valid in the case of applied scientific disciplines. D'Este and Iammarino (2010) highlight that research quality is slightly more important for the frequency of research partnerships in the basic sciences, relative to the applied ones. Lastly, Perkmann et al. (2011) find that industry involvement is positively related to faculty research quality within physical and engineering sciences when considering both the proportion of good researchers and the presence of star scientists; yet, in the medical and biological sciences the relationships becomes negative when considering star scientists; finally, in the social sciences, the authors find a negative relationship between industry involvement and research quality.

The relationship between research quality and academic engagement for the basic and applied sciences is driven by a number of elements that can be ascribed to the motivations for academic departments to collaborate with businesses. Firstly, the degree of internal resources available at department level plays a key role in shaping such motivations. As discussed in Sect. 2.1, interactions with industry in basic research is less likely to happen due to diverging research motivations: in this case, academic scientists may be motivated to pursue collaboration with industry only when there is a specific funding gap that limit their research productivity and quality. Lower tier departments specialised in basic sciences may push researchers to seek collaboration with industry in order to acquire additional research funds to compensate for their low financial capacity (Perkmann et al., 2013). In such cases, departments are arguably willing to overcome the diverging research missions with industry in order to attract funding from industrial partners. In other words, the need for financial resources modifies the incentives perceived by researchers so that they are willing to adapt their research mission and agenda to industry requirements. Conversely, research activity in higher quality departments is mostly directed at publishing in top-tier academic journals, and the higher level of resources available is tightly linked to such research output. Therefore, academics in those departments will work with firms only if the research pursued jointly will provide novel insights and ideas that will eventually result in published scientific research (Perkmann et al., 2011). In this case, the trade-off between researchers' and industry's research goals likely represents an important barrier that limits the alignment between motivations for collaboration.

An additional element informing the relationship between academic standing and collaboration with industry is provided by the department logic, namely the set of institutional norms and values governing science and research. In the basic sciences, U–I collaboration may be looked down because deemed to distract researchers' effort from fundamental questions and to modify their research agendas toward more applied research (Cohen & Randazzese, 1996; David, 2000). In addition, working with industry might generate time and resource pressures that reduce the ability to concentrate on academically relevant research outputs (Calderini et al., 2007). Higher-rated departments normally place higher value on academic output (Allison & Long, 1990; Crane, 1965) and hence tend to motivate academics to engage in blue sky research rather than in interactions with industry (Ponomariov, 2008). In other words, high levels of academic research quality in basic research may mirror a highly competitive academic environment that restricts scientists' willingness to interact with business. On the contrary, in lower tier departments of basic scientific disciplines, researchers may perceive less pressure to perform according to academic metrics and more enticement to collaborate with industry. In such latter case, the department institutional logic does not discourage U–I interaction, therefore alignment between motivations may be achieved more easily.

On the grounds of the above argumentations, we expect that the higher (lower) the academic standing of university departments belonging to basic sciences, the lower (higher) the extent of engagement with industry. Hence, we put forward the following hypothesis:

Hypothesis 1a Academic research quality negatively drives the extent of engagement with industry for departments of basic sciences.

In university departments of applied sciences, such as engineering, financial resources may play a limited role in the decision and extent of interaction with industry because the non-financial benefits of U–I interactions are clear. Applied scientists are mostly interested in the design, development and use of tangible artefacts, therefore they are by definition closely linked to industry technology development (Meyer-Khramer & Schmoch, 1998; Perkmann et al., 2011). As a consequence, the alignment of motivations for collaboration between researchers of applied sciences and businesses is favoured by similar and often converging research interests. For instance, applied researchers' search for industrial application of their inventions highly matches firms' product development strategies and objectives (Bodas-Freitas & Verspagen, 2017). Such alignment in research goals implies that engaging with industry has a substantial academic value, which may explain why high research quality in applied disciplines is likely to be associated with higher academic engagement (Balconi & Laboranti, 2006; Mansfield, 1995). For applied sciences departments of lower academic standing, although a lower degree of resources availability pushes researchers to seek for additional funding elsewhere, lower research quality may mirror a more difficult alignment between academic and industrial goals. In fact, firms normally search for the most skilled and highly reputed academic collaborators to work with, because the expected benefits from collaborative research are higher (Perkmann et al., 2011).

The department institutional logic in applied disciplines is similar to that in basic sciences as far as the evaluation of the research output (i.e. publications) is concerned, but differs from that as high reputation is attached to a wider commercialisation of the research results. Applied fields produce knowledge that is directly relevant for firms, hence making U–I collaboration essential (Balconi & Laboranti, 2006). In addition, collaboration with industry can boost researchers' performance because it expands the research agenda and increase the pool of new ideas (Banal-Estañol et al., 2015). Therefore, U–I interactions are positively regarded and departments will tend to motivate academics to engage in intense interactions with industry (Ponomariov, 2008). Given firms' search for the best academic partners to work with (Perkann et al., 2011), top applied sciences departments arguably achieve a strongest position for collaborating with firms as compared to low quality departments.

Following these considerations, we expect that the higher (lower) the academic standing of university departments belonging to applied sciences, the higher (lower) the extent of engagement with industry. Our second hypothesis is as follows:

Hypothesis 1b Academic research quality positively drives the extent of engagement with industry for departments of applied sciences.

2.3 The role of cumulated experience in academic engagement

Notwithstanding the importance of research quality, even across different scientific domains, this alone cannot fully explain the occurrence and level of U–I interaction. Past research has extensively focused on contextual factors that may affect the involvement of universities with firms, including geographical proximity (e.g. D'Este & Iammarino, 2010; D'Este et al., 2013), department and university size (Perkmann et al., 2013) and previous experience in academic engagement. With respect to the latter, studies carried out at the individual level find that the attitude of academics towards collaboration with industry is positively influenced by having collaborated in the past (e.g. D'Este & Patel, 2007; Van Dierdonck et al., 1990). Similarly, the likelihood of scientists' participation in academic engagement activities is positively influenced by previous experience in patenting and other commercialisation activities (Bekkers and Bodas-Freitas, 2008). In addition, empirical works show that the likelihood of scientists' interaction with industrial partners is positively related to the extent of involvement in grant-sponsored joint research (Bozeman & Gaughan, 2007; Link et al., 2007): academic scientists who are highly successful in procuring grants involving firms are more likely to maintain fruitful research agendas, which include those of interest to industry (Ponomariov, 2008). At the institutional level, Schartinger et al. (2002) note that when academic departments in a given scientific field have a high level of experience in external interactions, notably with industry, both institutional and individual barriers to knowledge interactions are likely to matter less than in the case of fields of science with little experience. Besides lowering barriers, previous knowledge interactions by university departments enlarge the network of potential contacts with industrial partners and hence increase the likelihood of future collaborations. Therefore, academic departments with established collaborations with companies reflect an institutional environment favouring interactions with industry (D'Este & Patel, 2007).

A positive association between experience and engagement in joint research activities between firms and universities may be driven by various factors from the business side as well. As already noted, "industrially" fruitful academic research agendas, lowered barriers to knowledge interactions, and enlarged network of contacts are among the key motives. In addition, companies tend to look positively at academic scientists, as well as departments and institutions, who have experience in procuring grants from public agencies, as this mirrors scientists' ability to secure funding allocated via competitive bids (including writing effective applications, gathering high quality human resources, establishing links with industrial partners, etc.). More generally, cumulated experience represents for firms an indirect measure of the "organisational climate" (Ponomariov, 2008): while universities with relatively low experience with industry may develop ad hoc and less routinised interactions, those with high levels of experience might be characterised by a rooted culture of interactions, hence resulting in institutional environments where linkages with industrial partners are "sanctioned, accepted, or even expected" (Ponomariov, 2008: 490).

Evidence on previous experience as a contextual determinant of academic engagement together with research quality is scanty. The literature does not account for academic research quality when estimating the relationship between the amount of cumulated academic experience in U–I interactions and future engagement. The existence of simultaneous effects of department experience and research quality is particularly interesting as the literature extensively shows that both factors play a major role in academic engagement, at the same time presenting inconclusive evidence on the net role of research quality. Thus, investigating the joint role of research quality and experience across different scientific disciplines may help explaining variation in the findings of the extant research and contribute to the literature on the topic.

We posit that cumulated experience negatively moderates the role of academic research quality in basic sciences departments and positively moderates it in the case of applied sciences academic departments. Given the relevance of experience in U–I interactions, we expect it to compensate for the lack of attractiveness that basic sciences departments of high quality may have for businesses. This is likely to be driven by lowered barriers to interactions and a favourable organisational climate linked to cumulated academic experience in U–I interactions, as well as to a documented track record of fruitful applications of research outputs (Ponomariov, 2008; Schartinger et al., 2002). In the case of applied sciences departments, research quality and experience both have a positive relationship with academic engagement, hence we expect that they reinforce each other. In addition, such reinforcement may be linked to the presence of past U–I connections that lead to strengthening existing collaborations while establishing new ones. Therefore, we expect that the higher the experience of basic (applied) sciences departments, the lower (higher) the negative (positive) influence of academic quality on the extent of engagement with industry. Accordingly, we hypothesise the following:

Hypothesis 2a Experience mitigates the negative relationship between research quality and academic engagement in the basic sciences.

Hypothesis 2b Experience amplifies the positive relationship between research quality and academic engagement in the applied sciences.

3 Data, variables and methodology

3.1 Data sources

The data for the empirical analysis consists of a set of U–I research grants awarded to UK Universities by the Engineering and Physical Sciences Research Council (EPSRC) between 1992 and 2007, combined with university and department level information gathered from the UK Higher Education Funding Councils' Research Assessment Exercise (RAE) 2001 and 2008.

The EPSRC is one of the UK research councils responsible for administering public funding for research.[2] It distributes more than 20% of the total UK science budget, being the largest council in terms of the volume of research funded (D'Este et al., 2013). It is responsible for funding research in the areas of engineering and physical sciences, including all the engineering fields, chemistry, mathematics and computer science, but it also welcomes research proposals that span the remits of other research councils, such as biology, social science or medical-related research. The EPSRC provides funding to national research through a wide range of grant schemes. In this work we consider U–I partnerships supported through standard grants and through the LINK grant scheme.[3] These

[2] In the academic year 2007/08, the UK Research Councils provided 36.5% of research grants and contracts, the largest share of the total (source: www.hesa.ac.uk).

[3] Collaboration from industry is encouraged but not mandatory under the standard grant schemes, thus we only consider projects where firms are involved. The LINK scheme instead specifically provided funding for collaborative research between at least one science-based organisation and one business partner. Around 70% of the partnerships supported between 1992 and 2007 by the EPSRC were funded under the Standard Research Grant Scheme, followed by the LINK grant scheme (10%).

partnerships aimed at contributing to joint upstream research for the creation of new knowledge and, therefore, they are far from industrial applications. They exclude contract research paid by the company to have a specific and well-defined outcome. UK Higher Education Institutions take the role of project coordinator (i.e. Principal Investigator) of each project, while collaborators from industry, commerce and other organisations are partners. The partnership selection process is managed by the EPSRC, which expects the partners to develop an agreement clarifying the respective contributions prior to the proposal submission.

The EPSRC dataset used here includes information on the number of U–I grants won by each academic department, the size of the grants, and the amount of cash or in-kind support (or a combination of both) provided by companies to the joint projects. In order to collect information on the research quality of UK academic department, we exploited the RAE, nowadays called research evaluation framework (REF), which is an evaluation exercise carried out approximately every 5 years. The primary purpose of the RAE is to provide ratings of research quality to be used by the UK higher education funding bodies in determining the level of university public funding. For evaluation by the RAE 2001 and 2008, universities submitted the results of their research activity for all or some fraction of the research staff in their departments, within 68 so-called Units of Assessment (UoA), corresponding to 68 subject research areas. Submission to the RAE is not mandatory but incentives for participation are high as public research funding tightly depends on the assessment. Besides department ratings, the RAE provides other information, including department size (count of staff) and amount as well as sources of research funding received during the period under evaluation.

These rankings have been extensively used in the academic literature focused on UK research quality (e.g. Abramovsky et al., 2007; Ambos, 2008; D'Este & Iammarino, 2010; D'Este & Patel, 2007; McGuinness, 2003; Perkmann et al., 2011). RAE results are considered reliable because they follow an expert review process conducted by assessment panels, whose members are nominated by a wide range of organisations. The nominated experts carry out a review process that evaluate the quality of the research output (refereed publications) submitted by each department on the basis of a set of criteria and working methods chosen for each specific field of research.[4,5]

Given the time frame of our EPSRC data, we combined it with two waves of the RAE: the RAE 2001, which evaluates academic research published in 1994–2000, and the RAE 2008, evaluating research output produced in 2001–2007. First, we link each academic department involved to a UoA[6]; secondly, we merge the data from the RAE 2001 and 2008.

[4] Each panel assesses research quality of various units of assessments (broadly corresponding to academic departments), all belonging to the same broad area of research; hence, the method is field-specific.

[5] The use of RAE/REF rankings for the purpose of evaluating academic quality has both advantages and disadvantages. While the RAE/REF results are generally considered reliable, they may only provide partial and imperfect information about the overall quality of Higher Education Institutions for various reasons. See, for instance Barker (2007), Martin (2011), Geuna and Piolatto (2016).

[6] Most academic departments clearly correspond to a UoA (e.g. departments of civil engineering, biological sciences, physics); in some cases, a choice had to be made on the most appropriate UoA for a given department, notably for interdisciplinary departments (e.g. departments of chemical and biological sciences). The choice was based on the distribution of academic staff across disciplines inside departments; information on this was obtained from the RAE as well as from manual searches on academic department webpages.

By doing so, for each academic department we put together information on the EPSRC grants and on the evaluation obtained in 2001 and in 2008, along with a set of information collected from the RAE data. The final dataset includes 280 university departments that took part in at least one EPSRC U–I partnership both in the period preceding the publication of the RAE 2001 and in the years preceding the publication of the RAE 2008.

3.2 Dependent variable

We measure U–I collaboration by the volume of funding that university departments receive from companies in the second period under investigation (2001–2007). We consider the total cumulated level of funding in the main analysis, while the average amount of funding per project is employed for a robustness check. Exploiting the level of private funding, as reported by the funding agency, allows to overcome limitations in prior research, mostly related to the use of indirect proxies of U–I collaboration (Perkmann et al., 2011, 2013).[7] Importantly, the amount of resources provided by private partners within collaborating projects provides a measurable account of the value that industry places on university knowledge. The mean value of the newly created dependent variable, *IndFund*, in the time period 2001–2007 is 1.5 million pounds, but it ranges from 0 (3 departments) to 15 million pounds (std. dev. 2.7 million) (see Table 1).

3.3 Independent variables

The submission of each department to the RAE 2001 was rated on a seven-point scale from 1 to 5*, with 5* being the highest score, indicating that research quality achieved international excellence in more than a half of the departments' submitted output, and the remaining output reached national excellence. The original scale was 1, 2, 3b, 3a, 4, 5 and 5* (see Table 2). While none of the departments received the lowest rating, over 50% (corresponding to 121) of departments in our sample were given the highest evaluation (5 and 5*).[8] To synthesize the rating while accounting for its distribution in our sample, we worked out two variables. The first one is a dummy indicator (*TopQual*) that takes value 1 if a department has obtained a rating of 5 or 5*. The independent variable so constructed allows to clearly distinguish between low-medium quality departments and top ones. However, given the concentration of departments in the highest ratings in our sample, we build an additional measure that allows to distinguish between departments whose research quality is extremely high from those whose quality is high. More specifically, we work out three quality levels measured through binary indicators, each taking value 1 if the original RAE 2001 rating equals 2–3b–3a–4 (*QualLevel_1*), 5 (*QualLevel_2*), and 5* (*QualLevel_3*)

[7] It should be noted that our dependent variable does not capture non-monetary and/or informal exchanges that do not result in actual income. In addition, the amount of industry funding mirrors directly the capability to get funded by the funding agency, besides the extent to which university and industry are interested in collaborating.

[8] This distribution shows that our sample displays a higher than the average research quality, as compared to the whole sample of UK Universities' departments, where the share of UoA receiving 5 or 5* is 37% (source: RAE2001).

Table 1 Variable list (N = 280)

Variable	Description (Source)	Mean	SD	Min	Max
Dep. var					
IndFund	Funding from companies for EPSRC collaborations in 2001–2007 (EPSRC)	1,517,703	2,688,188	0	1.5e+07
Indep. vars					
TopQual	0/1 dummy indicating departments of high/very high research quality (own elaboration from RAE 2001)	0.5250	0.5003	0	1
QualLevel_1	0/1 dummy indicating departments of medium research quality (own elaboration from RAE 2001)	0.4750	0.5002	0	1
QualLevel_2	0/1 dummy indicating departments of high research quality (own elaboration from RAE 2001)	0.3857	0.4876	0	1
QualLevel_3	0/1 dummy indicating departments of very high research quality (own elaboration from RAE 2001)	0.1393	0.3469	0	1
Basic	0/1 dummy indicating departments of basic sciences (own elaboration from RAE 2001)	0.3285	0.4705	0	1
Applied	0/1 dummy indicating departments of applied sciences (own elaboration from RAE 2001)	0.5964	0.4914	0	1
Other	0/1 dummy indicating departments of other disciplines (own elaboration from RAE 2001)	0.075	0.2338	0	1
Experience	Funding from EPSRC for U–I collaboration in 1992–2000 (EPSRC)	2,043,875	2,851,427	19,959.7	2.4e+07
Control vars					
TotIndFund	Total funding from private sources in 1992–2000 (RAE 2001)	1,122,886	1,812,440	0	1.37e+07
PublFund	Total funding from public sources that from EPSRC for U–I collaboration (RAE 2001)	1,135,152	2,871,275	0	4.48e+07
Size	count of research active staff at time of RAE submission (RAE 2001)	28.1571	22.6606	1	167
Dist	mean distance (in Km) between universities and collaborating firms in 1992–2000 (own elaboration)	192.9427	115.6085	0	596.1332
Eastmid	0/1 dummy indicating departments located in East Midlands	0.0821	0.2751	0	1
Easteng	0/1 dummy indicating departments located in East of England	0.0536	0.2256	0	1
London	0/1 dummy indicating departments located in London	0.1464	0.3542	0	1
Noreast	0/1 dummy indicating departments located in North East	0.0393	0.1946	0	1
Norwes	0/1 dummy indicating departments located in North West	0.0821	0.2751	0	1
Noirela	0/1 dummy indicating departments located in Northern Ireland	0.0250	0.1564	0	1
Scotlan	0/1 dummy indicating departments located in Scotland	0.1393	0.3469	0	1
Southea	0/1 dummy indicating departments located in South East	0.1214	0.3272	0	1
Southwe	0/1 dummy indicating departments located in South West	0.0786	0.2696	0	1
Wales	0/1 dummy indicating departments located in Wales	0.0536	0.2256	0	1
Westmid	0/1 dummy indicating departments located in West Midlands	0.0714	0.2580	0	1
Yorkhum	0/1 dummy indicating departments located in Yorkshire and the Humber	0.1071	0.3098	0	1

Table 2 Independent variable: quality profiles of academic departments (N = 280)

Rating RAE 2001	Freq	%	Cum	*QualLevel_*
2	1	0.36	0.36	1
3a	36	12.86	13.21	1
3b	14	5.00	18.21	1
4	82	29.29	47.50	1
5	108	38.57	86.07	2
5*	39	13.93	100.00	3
Total	280	100.00		

Table 3 Independent variable: scientific disciplines of academic departments (N = 280)

Dept. scientific area	Freq	%	Cum
Applied	167	59.64	59.64
Basic	92	32.86	92.50
Other	21	7.50	100.00
Total	280	100.00	

Table 4 Independent variables: quality levels and scientific disciplines of academic departments (N = 280)

	Full sample (%)	Basic (%)	Applied (%)
QualLevel_1	47.5	33.7	50.9
QualLevel_2	38.57	48.91	35.33
QualLevel_3	13.93	17.39	13.77

respectively. The three dummies identify departments of low-medium research quality (*QualLevel_1* = 1 for 47.5% of departments), of high research quality (*QualLevel_2* = 1 for 38.57% of departments) and of very high research quality (*QualLevel_3* = 1 for 13.93% of departments). We employ *QualLevel_2* and *QualLevel_3* as independent variables in the regression analyses, while *QualLevel_1* is the reference category, hence omitted from the model.

Besides academic quality, to test hypotheses 1a and 1b we exploit two binary variables indicating whether departments belong to basic or applied sciences at the time of the RAE 2001 submission. The variable *Basic* (32.86%) equals 1 for chemistry, physics, maths and statistics, while *Applied* (59.64%) is equal to 1 for all the engineering related sciences,[9] computer science and environmental sciences (see Table 3). The remaining departments belong to the field of social sciences and humanities (5.36%)[10] and medical sciences (2.14%)[11]: since these are a minority in our sample, we group them under the binary indicator *OtherDisc* (7.5%).[12] As far as research quality is concerned, the distribution of the

9 General, chemical, civil, electric, mechanic, and metallurgy and materials engineering.

10 Arts, architecture, planning, management, and communication studies.

11 Medical and pharmaceutical studies, and biology.

12 We decided to keep the observations in the sample of non-basic and non-applied departments as this allows to test the relationship between the basic/applied dummy indicators and the dependent variable in the same model. The results are robust to the exclusion of those observations.

Table 5 Independent variables: experience in U–I collaboration across quality levels and scientific disciplines of academic departments (N = 280)

	Mean (mln GBP)	SD (mln GBP)	Freq
Experience across quality levels			
QualLevel_1	1157899.4	1699070.7	133
QualLevel_2	2061063.6	2168080.3	108
QualLevel_3	5017683.2	4960621.8	39
Experience across disciplines			
Applied	2301339.4	3242856	167
Basic	1847308	2226634.8	92

quality indicators across basic and applied disciplines is slightly different (see Table 4). While the majority of basic sciences departments (66%) was given a high to highest quality rankings, less than half of applied sciences departments (49%) received similar ratings.

In order to test hypotheses 2a and 2b, we measure departmental cumulated experience in academic engagement, using the volume of EPSRC funds awarded in previous years for U–I partnerships (*Experience*). This variable measures experience that departments gain in carrying out research funded by the EPSRC, hence it helps understanding whether and to what extent factors such as lowered barriers to interactions, supportive organisational climate inside academia and the ability to mobilise resources resulting from past involvement in grant-sponsored joint research, affect the role played by research quality within a given scientific field.[13] The mean volume of funding received from the EPSRC by each department for U–I projects that took place in 1992–2000 is 2 million GBP (std. dev. 2.8 million GBP) (see Table 1). When looking at the level of cumulated experience across quality levels and scientific disciplines of academic departments, we observe an upward trend with increasing quality (Table 5, top panel) and larger experience among applied sciences departments with respect to basic ones (Table 5, bottom panel).

[13] Past EPSRC funding may be related to academic standing because better departments may have higher interaction with public funding agencies, hence capturing a very similar effect to that of *Research quality* on industry funding. Similarly, the quality rating of each department may be influenced by having participated to EPSRC projects. However, we believe this not to be a major concern in our analysis due to the ways public funding for research is allocated to UK universities. During the time period under analysis, public research funding in UK higher education was administered under a 'dual support' system, according to which Higher Education Funding Councils provided the so-called block grant funding to support the research infrastructure, and the Research Councils as well as other entities (e.g. charities, the European Union and government departments) provided grants for specific research projects and programmes. The block grant funding was allocated on the basis of research quality, as evaluated by the higher education funding councils themselves in the RAE. Ad-hoc grants for specific projects were instead allocated on the basis of different criteria. Therefore, the amount of EPSRC funding that each department received between 1992 and 2000 is supposed to be independent from research quality in those years, as evaluated by the RAE 2001. Moreover, the RAE ratings were published in 2001, whereas we only include EPSRC funding received up to 2000 as a measure of previous experience.

3.4 Control variables

We include a number of controls in the attempt to properly isolate the relationships between the dependent and independent variables (Table 1). In the first place, to account for other streams of funding that each department received from the private sectors and that may be related to the volume of funds raised from industry through the EPSRC collaboration schemes, we control for the level of total private funding obtained in the period 1992–2000 (*TotIndFund*). Second, we control for the amount of public funding received in the years 2001–2008, including streams of funds from the government and the Research Councils, but excluding those received by the EPSRC (*PublFund*). We expect both *TotIndFund* and *PublFund* to be positively related to the dependent variable since departments that raise funds from various sources are also likely to raise higher levels of funds specifically from companies (Boardman & Ponomariov, 2009; Bozeman & Gaughan, 2007). Third, we control for department size by adding the count of research active staff in the department at the time of the RAE 2001 submissions (*Size*). We expect larger departments to access higher amounts of industry funding because of a likely larger pool of researchers engaged in collaboration with industry.

Importantly, we also introduce a set of binary indicators to account for the geographical location of the academic departments under investigation. The following region level dummies are included: East Midlands, East of England, London, North East, North West, Northern Ireland, Scotland, South East, South West, Wales, West Midlands and Yorkshire and the Humber. These captures region level factors that may affect the level of academic engagement with industry, including: local exogenous shocks, such as regulatory changes; the establishment of new companies, which enlarges the pool of firms to be potentially involved into U–I knowledge transfer; regional economic conditions, such as local innovative firms' absorptive capacity; quality of the labour market; and the implementation of new regional as well as national policies (Lawton Smith & Bagchi-Sen, 2012). In addition to location dummies, we add to the list of control variables the mean distance (in Km) between universities and collaborating firms calculated on the sample of partnerships occurred in the period 1992–2000 (*Dist*). The average geographical distance between universities and firms allows to check for the role of geographical proximity as a predictor of future collaborations. Descriptive statistics for all variables are presented in Tables 1, 2, 3, 4 and 5, while the correlation matrix is reported in Table 11 in "Appendix".

3.5 Methodology

We estimate two models that allow to test hypotheses 1a and 1b, and hypotheses 2a and 2b, respectively. In the first model, we test the interaction effect between research quality and the basic or applied sciences dummy variables. This allows to investigate whether departmental academic standing is negatively related to engagement with industry for basic sciences departments and positively related to that for applied sciences departments. In the second model, we run a split sample analysis on the two sub-samples of basic (N = 92) and applied (N = 167) disciplines departments to test the interaction effect between research quality and cumulated departmental experience, as per hypotheses 2a and 2b. By doing so, we intend to specifically test the argument that experience has a moderation effect on research quality that differs across scientific domains.

Since the dependent variable is continuous, we estimate OLS regressions with robust standard error to account for potential heteroskedasticity of the error terms (Angrist & Pischke, 2008). To reduce endogeneity concerns due to simultaneity of cross-sectional data, we exploit the two time periods that resulted from combining the EPSRC dataset with the RAE 2001 and 2008. Therefore, we estimate the extent of U–I collaborations during 2001–2007 as a function of academic standing, scientific disciplines, experience and other control factors pertaining to the 1992–2000 period. We test for the presence of multicollinearity using Variance Inflation Factors (VIFs) for all model specifications and the results are satisfactory. The VIFs are always fairly low (below 2) with the exception of the interaction and interacted terms. Given the skewness of some of the continuous variables, we transform all of them through an inverse hyperbolic sine transformation that allows to linearise their trends, similarly to a logarithmic transformation, but avoid losing zero observations.[14]

4 Results

4.1 Main results

Tables 6 and 7 show the main findings. In Table 6 we present the results of the OLS regressions testing hypotheses 1a and 1b, while the results of the split sample analysis carried out to test hypotheses 2a and 2b are shown in Table 7. Column (1) in Table 6 includes only the control variables. Columns (2) and (3) include the binary indicator *TopQual* as a measure of department level academic quality, along with its interactions with the variables *Basic* [column (2)] and *Applied* [column (3)], respectively. In columns (4) and (5) research quality is measured with the dummy variables *QualLevel_2* and *QualLevel_3*, and their interactions with the *Basic* and *Applied* dummies are added to test hypotheses 1a and 1b. Similarly, in Table 7 we test hypotheses 2a and 2b exploiting *TopQual* and its interaction with *Experience* in columns (1) and (2); and *QualLevel_1* and *QualLevel_*2, along with their interactions with *Experience*, in columns (3) and (4).

The academic standing of UK universities is positively and significantly linked to the level of industry funding raised through EPSRC U–I partnerships, as can be noted from the coefficients of *TopQual* and *QualLevel_1* and *QualLevel_2* in columns (2) and (4) of Table 6. However, the additional effect of quality for departments of basic sciences (*TopQual*Basic*) appears to be negative and significant (at 5% level), while it is positive and highly significant for departments of applied disciplines (*TopQual*Applied*) (at 1% level). Similarly, the effect of increasing quality levels, with respect to the baseline *QualLevel_1*, is increasingly negative for departments in the basic sciences and increasingly positive for those in the applied sciences, as the coefficients of the interaction terms in columns (4) and (5) show. This suggests that academic research quality negatively drives the extent of engagement with industry among departments of basic sciences, as postulated in hypothesis 1a, while it drives it positively for departments in applied sciences, as per hypothesis 1b.

[14] This is an alternative to the Box-Cox transformations, defined by the following formula: $inverse\ y = \log\left[y_i + \left(y_i^2 + 1\right)^{\frac{1}{2}}\right]$. Except for very small values of y, the inverse sine can be interpreted as a standard logarithmic variable. However, unlike a logarithmic variable, the inverse hyperbolic sine is defined at zero (e.g. Burbidge et al., 1988; Johnson, 1949; MacKinnon & Magee, 1990).

Table 6 OLS regressions Hp 1a and 1b. Dep. Var.: *IndFund*

Variables	(1) Full sample *IndFund*	(2) Full sample *IndFund*	(3) Full sample *IndFund*	(4) Full sample *IndFund*	(5) Full sample *IndFund*
TopQual		0.624*	−0.615		
		(0.322)	(0.421)		
QualLevel_2				0.582*	−0.633
				(0.325)	(0.449)
QualLevel_3				0.873**	−0.430
				(0.417)	(0.487)
Basic		1.013*	0.792	1.015*	0.794
		(0.562)	(0.520)	(0.564)	(0.523)
Applied		0.498	0.210	0.492	0.211
		(0.520)	(0.540)	(0.520)	(0.543)
*TopQual*Basic*		−1.228**			
		(0.510)			
*TopQual*Applied*			1.349***		
			(0.500)		
*QualLevel_2*Basic*				−1.202**	
				(0.556)	
*QualLevel_3*Basic*				−1.299**	
				(0.557)	
*QualLevel_2*Applied*					1.335**
					(0.539)
*QualLevel_3*Applied*					1.348**
					(0.554)
Experience	0.818***	0.729***	0.739***	0.715***	0.728***
	(0.112)	(0.119)	(0.117)	(0.124)	(0.122)
TotIndFund	0.100	0.101*	0.100*	0.101	0.0996
	(0.0610)	(0.0612)	(0.0606)	(0.0612)	(0.0606)
PublFund	0.0149	0.0154	0.0172	0.0181	0.0194
	(0.0448)	(0.0437)	(0.0431)	(0.0435)	(0.0431)
Size	0.350	0.392	0.374	0.361	0.346
	(0.269)	(0.258)	(0.254)	(0.261)	(0.258)
Dist	−0.171	−0.174	−0.181	−0.166	−0.174
	(0.153)	(0.159)	(0.158)	(0.161)	(0.160)
Eastmid	0.643	0.724	0.776	0.758	0.806
	(0.567)	(0.567)	(0.567)	(0.579)	(0.580)
Easteng	0.608	0.636	0.662	0.620	0.647
	(0.447)	(0.470)	(0.468)	(0.467)	(0.466)
Noreast	0.432	0.499	0.522	0.531	0.544
	(0.620)	(0.617)	(0.615)	(0.621)	(0.618)
Norwest	0.523	0.504	0.517	0.524	0.533
	(0.528)	(0.536)	(0.535)	(0.539)	(0.538)
Noirela	0.949*	0.966*	0.964*	1.002*	0.996*
	(0.559)	(0.539)	(0.545)	(0.550)	(0.556)

Table 6 (continued)

Variables	(1) Full sample *IndFund*	(2) Full sample *IndFund*	(3) Full sample *IndFund*	(4) Full sample *IndFund*	(5) Full sample *IndFund*
Scotlan	0.0953	0.171	0.213	0.202	0.242
	(0.498)	(0.501)	(0.501)	(0.508)	(0.509)
Southea	0.164	0.180	0.182	0.165	0.173
	(0.613)	(0.615)	(0.612)	(0.620)	(0.618)
Southwe	0.803	0.855*	0.920*	0.859*	0.923*
	(0.501)	(0.502)	(0.515)	(0.505)	(0.519)
Wales	0.484	0.477	0.485	0.503	0.510
	(0.685)	(0.688)	(0.680)	(0.693)	(0.686)
Westmid	0.863*	0.826*	0.821*	0.841*	0.836*
	(0.497)	(0.496)	(0.494)	(0.500)	(0.498)
Yorkhum	0.418	0.454	0.472	0.458	0.481
	(0.491)	(0.475)	(0.466)	(0.481)	(0.471)
Constant	−0.686	−0.274	−0.0956	−0.0500	0.0754
	(1.436)	(1.390)	(1.389)	(1.446)	(1.444)
Observations	280	280	280	280	280
R-squared	0.361	0.380	0.384	0.381	0.385
Adj R-squared	0.322	0.332	0.336	0.328	0.332
F	10.96	9.182	9.485	12.18	12.22
Prob > F	0	0	0	0	0
LogLikelihood	−581.4	−577.1	−576.2	−576.9	−576.1
LogLikelihood costant-only model	−644.1	−644.1	−644.1	−644.1	−644.1

Robust standard errors in parentheses (***$p < 0.01$, **$p < 0.05$, *$p < 0.1$)

QualLevel_1, *Other* and *London* omitted because of collinearity

Figure 1 shows the predictive margins of the dependent variable for the interaction terms presented in Table 6. The graph (a) shows that the level of industry funding obtained by departments in basic sciences is higher for non-top quality departments (blue line) with respect to top ones (red line). On the contrary, graph (b) shows that top quality departments (red line) in applied disciplines have access to a higher level of industry funding with respect to non-top ones (blue line). Similarly, the graphs at the bottom of Fig. 1 show that higher research quality among basic sciences departments leads to lower industry funding [see graph (c)]—although it should be noted that having a 5* rating (green line) is better than being assigned 5 (red line)—while higher rankings for applied sciences departments brings consistently higher levels of industry funding [see graph (d)]. The graphs further confirms the findings from Table 6, hence supporting hypotheses 1a and 1b.

The level of cumulated experience (*Experience*) is positively and significantly related to industrial funding raised by academic departments in every estimation of Table 6, hence supporting the argument that the former may play a key role in facilitating the link between research quality and academic engagement. The results from the split sample analysis displayed in columns (1) and (3) of Table 7 show that experience positively moderates the influence that academic quality has on basic sciences departments' engagement with industry, hence mitigating the negative relationship ascertained in Table 6, confirming

Table 7 OLS regressions Hp 2a and 2b. Dep. Var.: IndFund

Variables	(1) Basic sciences *IndFund*	(2) Applied sciences *IndFund*	(3) Basic sciences *IndFund*	(4) Applied sciences *IndFund*
TopQual	−13.34***	−1.971		
	(4.741)	(2.955)		
QualLevel_2			−14.52***	−1.262
			(5.405)	(3.572)
QualLevel_3			−11.29**	−1.815
			(5.310)	(4.495)
Experience	0.320	0.540***	0.318	0.543***
	(0.292)	(0.199)	(0.295)	(0.200)
*TopQual*Experience*	0.881***	0.191		
	(0.321)	(0.198)		
*QualLevel_2*Experience*			0.964**	0.140
			(0.366)	(0.241)
*QualLevel_3*Experience*			0.721**	0.191
			(0.356)	(0.288)
TotIndFund	0.120	0.0815	0.124	0.0826
	(0.106)	(0.0849)	(0.109)	(0.0860)
PublFund	0.0663	−0.00286	0.0574	−0.000994
	(0.0982)	(0.0511)	(0.0975)	(0.0513)
Size	0.127	0.485	0.187	0.465
	(0.290)	(0.450)	(0.284)	(0.445)
Dist	−0.523**	0.231	−0.543**	0.234
	(0.217)	(0.316)	(0.227)	(0.319)
Eastmid	−0.407	1.695**	−0.608	1.716**
	(0.766)	(0.764)	(0.906)	(0.769)
Easteng	0.208	0.765	0.249	0.744
	(0.875)	(0.671)	(0.878)	(0.685)
Noreast	0.441	0.214	0.415	0.236
	(1.054)	(0.753)	(1.280)	(0.767)
Norwest	0.647	−0.0245	0.527	−0.0172
	(0.868)	(0.674)	(0.934)	(0.680)
Noirela	2.242***	0.0172	2.053***	0.0430
	(0.648)	(0.731)	(0.774)	(0.746)
Scotlan	0.776	−0.270	0.634	−0.258
	(1.038)	(0.639)	(1.142)	(0.651)
Southea	0.315	−0.199	0.277	−0.235
	(0.646)	(0.974)	(0.686)	(1.017)
Southwe	0.831	0.712	0.750	0.704
	(0.858)	(0.647)	(0.909)	(0.653)
Wales	−0.835	0.434	−1.014	0.436
	(1.403)	(0.831)	(1.501)	(0.839)
Westmid	−0.227	0.961	−0.470	0.952
	(1.009)	(0.630)	(1.144)	(0.631)

Table 7 (continued)

Variables	(1) Basic sciences *IndFund*	(2) Applied sciences *IndFund*	(3) Basic sciences *IndFund*	(4) Applied sciences *IndFund*
Yorkhum	−0.00225	0.584	−0.188	0.557
	(1.017)	(0.540)	(1.123)	(0.544)
Constant	8.917**	0.759	9.029**	0.731
	(4.068)	(3.017)	(4.112)	(3.034)
Observations	92	167	92	167
R-squared	0.532	0.403	0.535	0.404
Adj R-squared	0.417	0.331	0.405	0.322
F	9.768	11.91	10.58	15.26
Prob > F	0	0	0	0
LogLikelihood	−180.9	−338.5	−180.6	−338.4
LogLikelihood costant-only model	−215.8	−381.6	−215.8	−381.6

Robust standard errors in parentheses (***$p<0.01$, **$p<0.05$, *$p<0.1$)

QualLevel_1 and *London* omitted because of collinearity

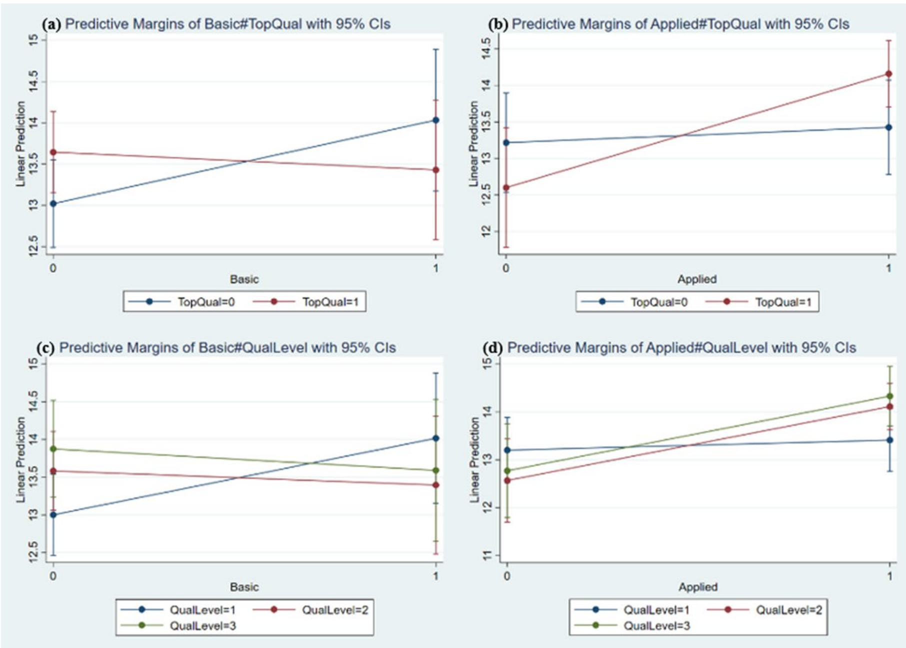

Fig. 1 Predictive margins of interaction terms in Table 6: **a** Basic*TopQual [Col. (2)]. **b** Applied*TopQual [Col. (3)]. **c** Basic*QualLevel [Col. (4)]. **d** Applied*QualLevel [Col. (5)] (Color figure online)

hypothesis 2a. Therefore, our data suggest that the larger the extent of cumulated experience in academic engagement among basic sciences departments, the lower the influence of academic research quality on industrial funding obtained through U–I collaborations.

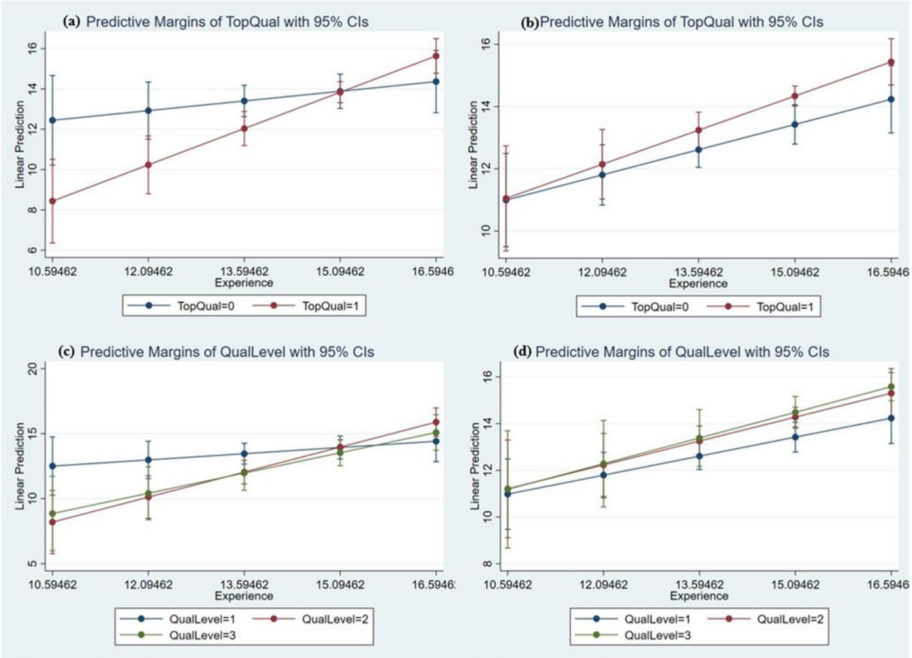

Fig. 2 Predictive margins of interaction terms in Table 7: **a** Experience*TopQual for Basic sciences departments [Col. (1)]. **b** Experience*TopQual for Applied sciences departments [Col. (2)]. **c** Experience*QualLevel for Basic sciences departments [Col. (3)]. **d** Experience*QualLevel for Applied sciences departments [Col. (4)] (Color figure online)

Instead, the amplification effect of experience postulated in hypothesis 2b with respect to applied sciences departments is only qualitatively confirmed, in that the coefficients of the interaction terms in columns (2) and (4) are positive but not significant.

Figure 2 shows the predictive margins for the interaction terms displayed in Table 7.[15] Graphs (a) and (c) show the plots of the statistically significant coefficients [columns (1) and (3) in Table 7]. For increasing levels of experience in U–I collaboration for departments in basic sciences [graph (a)], both top and non-top quality departments obtain increasing levels of industry funding. In particular, for lower levels of past experience, non-top quality departments in basic sciences have higher predicted levels of industry funding, hence mitigating the negative relationship between research quality and academic engagement; however, for very high levels of past experience, the opposite holds, showing that top quality departments in basic sciences access higher levels of industry funding with respect to non-top departments. Similarly, a mitigation effect due to increasing levels of experience is shown in graph (c), where lower quality departments in basic sciences have higher levels of industry funding with respect to top quality departments, while the opposite happens when cumulated past experience reaches high levels. These graphs confirm the mitigation effect postulated in hypothesis 2a. Additionally, they show that such effect seems not to

[15] Experience is on the horizontal axis, its values ranges between the minimum and maximum of the IHS-transformed variable.

hold for the right-hand side of the distribution of the variable *Experience*, hence for quite high levels of cumulated experience in U–I collaboration: experience does not mitigate the relationship between research quality and academic engagement for basic sciences departments when the former reaches a threshold of 1.8 million GBP of past EPSRC funds.[16]

Among the control variables, it is worth noticing the positive and significant coefficient of *TotIndFund* in Table 6, showing the tight relationship between various sources of funding from industrial partners, and the negative link between geographical distance and the dependent variable in Table 7, proving that importance of physical proximity for U–I collaborations in basic sciences. The location dummies show that only few regions do better than the baseline category (*London*) in terms of engagement with industry, which may be driven by few key departments in universities there located.

4.2 Robustness checks

In order to check the robustness of our results, we carry out two sets of regressions. Firstly, we estimate the models displayed in Tables 6 and 7 after employing a different dependent variable. We modify the dependent variable *IndFund* by dividing it for the count of collaborative projects that each academic department joined in the time frame 2001–2007, hence obtaining the average level of industrial funding received per grant (*IndFundGrant*). The new dependent variable allows to check whether the hypothesised effects hold when accounting for the amount of funding obtained for each project (on average). Therefore, the first robustness check is aimed at uncovering whether the relationships between research quality and academic engagement—and their discipline-related effects—hold at project level (within each department), besides being found at aggregate department level.

The second set of regressions makes use of a differently coded measure of departmental academic standing, so to check the sensitivity of the results with respect to the previously employed measures of research quality. To construct a new variable, we exploit the median value of the original RAE 2001 rating, after transforming it to a proper 7-point scale variable.[17] Hence, we work out a binary indicator called *TopQualNew* equalling 1 for departments whose rating is above the median value, 0 otherwise. Given the rather different distribution of the RAE 2001 rating across disciplines, we exploit the median of each sub-group of departments (basic sciences, applied sciences, social sciences and humanities, and medical sciences).[18] This robustness check is useful because recoded variables like the measures of research quality employed in this work are partly subjective and hard to validate. Comparing the estimates obtained using differently coded variables allows to check both for the robustness of the results and for the reliability of the quality measures.

The results shown in Tables 8 and 9 are highly in line with those from Sect. 4.1, with the exception of a slightly different magnitude of the coefficients. Therefore, the first set of the robustness checks implemented confirms a negative relationship between research quality and academic engagement in the basic sciences (hypothesis 1a), a positive relationship in

[16] Out of 92 academic departments in basic sciences, 30 have a cumulated past experiences higher than the identified threshold (1.8 m GBP).

[17] The original RAE 2001 rating (1, 2, 3b, 3a, 4, 5, 5*) becomes a 7-point scale (1, 2, 3, 4, 5, 6, 7), from which it is possible to work out its median value.

[18] The tabulation of *TopQualNew* shows that 107 academic departments have received a higher than the median RAE 2001 ranking.

Table 8 Robustness check: OLS regressions Hp 1a and 1b. Dep. Var.: *IndFundGrant*

Variables	(1) Full sample *IndFundGrant*	(2) Full sample *IndFundGrant*	(3) Full sample *IndFundGrant*	(4) Full sample *IndFundGrant*
TopQual	0.322	−0.726**		
	(0.262)	(0.368)		
QualLevel_2			0.292	−0.772*
			(0.254)	(0.400)
QualLevel_3			0.527	−0.362
			(0.370)	(0.354)
Basic	0.790*	0.580	0.788*	0.567
	(0.465)	(0.401)	(0.463)	(0.407)
Applied	0.185	−0.0905	0.180	−0.0964
	(0.374)	(0.397)	(0.372)	(0.398)
*TopQual*Basic*	−1.033**			
	(0.443)			
*TopQual*Applied*		1.158***		
		(0.418)		
*QualLevel_2*Basic*			−1.051**	
			(0.476)	
*QualLevel_3*Basic*			−0.882*	
			(0.509)	
*QualLevel_2*Applied*				1.184***
				(0.446)
*QualLevel_3*Applied*				0.927*
				(0.499)
Experience	0.0886	0.0944	0.0662	0.0770
	(0.113)	(0.113)	(0.119)	(0.119)
Constant	7.129***	7.344***	7.415***	7.584***
	(1.281)	(1.259)	(1.308)	(1.293)
Control variables	Yes	Yes	Yes	Yes
Observations	239	239	239	239
R-squared	0.205	0.212	0.208	0.215
Adj R-squared	0.136	0.144	0.131	0.139
F	2.114	2.389	2.752	2.882
Prob > F	0	0	0	0
LogLikelihood	−430.7	−429.6	−430.3	−429.3
LogLikelihood costant-only model	−458.2	−458.2	−458.2	−458.2

Robust standard errors in parentheses (***$p < 0.01$, **$p < 0.05$, *$p < 0.1$)

the applied sciences (hypothesis 1b), and a moderation effect of experience on departmental quality in the basic sciences only (hypothesis 2a).

Table 10 shows the results of the robustness check implemented after creating the dichotomous indicator *TopQualNew*. A negative relationship between industrial funding for U–I collaboration and academic standing for departments of basic sciences is

Table 9 Robustness check: OLS regressions Hp 2a and 2b. Dep. Var.: *IndFundGrant*

Variables	(1) Basic sciences *IndFundGrant*	(2) Applied sciences *IndFundGrant*	(3) Basic sciences *IndFundGrant*	(4) Applied sciences *IndFundGrant*
TopQual	−14.46**	0.138		
	(5.455)	(2.193)		
QualLevel_2			−17.04***	1.372
			(6.312)	(2.379)
QualLevel_3			−3.497	−1.369
			(5.721)	(4.068)
Experience	−0.319	0.112	−0.389	0.103
	(0.344)	(0.186)	(0.364)	(0.191)
*TopQual*Experience*	0.943**	0.0337		
	(0.365)	(0.150)		
*QualLevel_2*Experience*			1.124**	−0.0545
			(0.425)	(0.162)
*QualLevel_3*Experience*			0.220	0.141
			(0.375)	(0.270)
Constant	14.93***	6.832***	15.68***	6.848***
	(4.130)	(2.517)	(4.385)	(2.557)
Control variables	Yes	Yes	Yes	Yes
Observations	82	138	82	138
R-squared	0.445	0.236	0.475	0.241
Adj R-squared	0.297	0.128	0.314	0.118
F	4.428	2.851	4.381	2.918
Prob > F	0	0	0	0
LogLikelihood	−146.5	−229.5	−144.1	−229.1
LogLikelihood costant-only model	−170.6	−248.1	−170.6	−248.1

Robust standard errors in parentheses (***$p<0.01$, **$p<0.05$, *$p<0.1$)

confirmed, along with a positive relationship for the departments of applied disciplines. The moderation effect of cumulated experience in academic engagement is only qualitatively confirmed, as the coefficients of the interaction terms in columns (3) and (4) are positive but not statistically significant.

5 Discussion and conclusion

This paper investigated the relationship between university departments' characteristics and academic engagement with businesses in the form of U–I collaboration. We focussed on the role of the quality profile of academic departments and on their cumulated experience in academic engagement as determinants of the extent of involvement in U–I collaboration. We postulated that the role of both factors is tightly linked to the scientific disciplines of academic departments, specifically considering differences between the basic and the applied hard sciences. The investigation of such issues is grounded on the pervasive role

Table 10 Robustness check: OLS regressions Hp 1a, 1b, 2a, 2b. Quality measure: *TopQualNew*

Variables	(1) Full sample *IndFund*	(2) Full sample *IndFund*	(3) Basic sciences *IndFund*	(4) Applied sciences *IndFund*
TopQualNew	0.536	−0.899	−8.760	−0.859
	(0.325)	(0.578)	(5.568)	(3.006)
Basic	1.254**	0.371		
	(0.567)	(0.603)		
Applied	0.881*	−0.146		
	(0.527)	(0.625)		
Experience	0.731***	0.721***	0.806***	0.526**
	(0.125)	(0.123)	(0.243)	(0.234)
*TopQualNew*Basic*	−1.352**			
	(0.677)			
*TopQualNew*Applied*		1.648***		
		(0.598)		
*TopQualNew*Experience*			0.536	0.113
			(0.365)	(0.207)
Constant	0.507	1.459	3.242	2.048
	(1.262)	(1.240)	(2.898)	(2.756)
Control variables	Yes	Yes	Yes	Yes
Observations	239	239	82	138
R-squared	0.389	0.399	0.500	0.449
Adj. R-squared	0.336	0.347	0.367	0.371
F	9.224	9.700	6.360	11.63
Prob > F	0	0	0	0
LogLikelihood	−479.9	−477.9	−163.8	−261.7
LogLikelihood costant-only model	−538.8	−538.8	−192.2	−302.9

Robust standard errors in parentheses (***$p<0.01$, **$p<0.05$, *$p<0.1$)

that U–I interactions have acquired in the current knowledge-based competitive context, where academic institutions are undoubtedly considered key agents of technological, scientific and economic progress, and companies rely more and more on the scientific output of academic research activities to compete in the globalised markets.

The findings show a negative relationship between the research standing of basic sciences academic departments, as measured by the RAE 2001, and the extent of involvement in U–I collaboration with companies—measured by the volume of private funding injected into U–I research partnerships during the period 2001–2007. On the contrary, a positive link holds in applied sciences departments. Finding a negative relationship between research quality and academic engagement contradicts most extant research, but is in line with few previous studies that find support for a negative relationship in specific contexts (D'Este & Patel, 2007; Mansfield & Lee, 1996; Perkmann et al., 2011; Ponomariov, 2008). On the one hand, low resource availability at lower quality universities may push researchers to seek industry collaboration to acquire research funds, hence overcoming diverging motivations for collaboration and lack of synergies between academia and firms. On the other hand, a more prestigious research environment may provide academics in top departments of basic sciences greater incentives to engage in blue-sky research rather than engaging with industry. A positive link between the quality profile of applied sciences academic departments and their engagement in research activity with industrial partners is in line with previous studies (e.g. Balconi & Laboranti, 2006; Mansfield, 1995) and is mostly due to the high match between research objectives and, especially, motivations for interaction between academia and firms.

Moreover, the analysis supports and extends the scant empirical evidence on the key role of experience in academic engagement, by showing that it acts as a moderating factor in the relationship between research quality and U–I collaboration. In particular, we find that the higher the level of departmental cumulated experience in academic engagement, the weaker the negative relationship between research quality and U–I collaboration in the basic sciences. Yet, such moderation effect does not hold for very high levels of departmental experience: when academic departments reaches a given amount of past experience, the effect of the latter is so strong that the relationship between their research quality and academic engagement turns positive. Conversely, we do not find significant moderation effects of experience with respect to the applied sciences. Arguably, the effect of experience is not pivotal in the case of applied sciences departments, where a strong positive relationship between research quality and academic engagement is likely to hold regardless the level of previous U–I interactions. Importantly, the acquisition of experience at department level may represent an incentive for companies, even when research is characterised by low market applicability as in basic sciences departments, because it lowers barriers to interactions and creates a favourable institutional environment (Antonioli et al., 2017; D'Este & Patel, 2007; Schartinger et al., 2002).

The analysis here presented is not free from limitations, primarily related to the two-time period setting, which does not fully rule out endogeneity concerns deriving from the likely bidirectional link between academic engagement and research quality, as well as experience. In addition, given the focus on one specific channel of U–I interaction, namely formalised joint research partnerships, our findings may not be straightforwardly extended to other channels—most notably the less formalised ones. Yet, it is worth underlining that U–I research collaborations are extremely widespread in many advanced countries and represent one of the most used policy tools to support U–I knowledge transfer. The choice to study U–I partnerships sponsored by the EPSRC, hence excluding other sources of U–I grants, may represent an additional limitation, because both universities and companies normally receive a multitude of public funding to conduct joint R&D activities. However, given that the EPSRC had a predominant role in R&D funding in the period under analysis, its case can be easily considered a representative one.

Notwithstanding, this work provides interesting associations between academic engagement and the quality of academic research as well as the level of experience, hence contributing to the innovation literature on U–I linkages. Firstly, we show the importance of analysing the joint effect of various determinants of academic engagement, in line with studies suggesting that factors like research quality do not unambiguously affect any form of academia-industry interaction (D'Este & Iammarino, 2010). Our findings highlight that the so-called *disciplinary-effects* are intertwined with other determinants, such as the extent of experience and research quality. Secondly, our work underscores that some of the key dynamics behind U–I interactions take place within academic departments. While the role of individual-level factors determining academic engagement is well explored in the literature, our analysis emphasizes that department values, culture and policies play a major role in influencing researchers' attitude towards engagement with industry, hence pointing to the relevance of collective research efforts and local culture.

This research also highlights some key factors that policy makers should take into account when aiming at supporting U–I interactions. First, differences between academic disciplines in the patterns of academic engagement should be accounted for by policy makers and universities. Second, a negative relationship between research quality and university engagement with industry in the basic sciences may result in the *adverse selection* of academic institutions into cooperation with businesses. Accordingly, lower quality institutions sort into collaborating with firms and, it follows, firms get access to lower quality research. This could be potentially detrimental to the value of academic engagement for firms and for the society more generally. Yet, it should be noted that researchers within low quality institutions often seek industry collaboration in order to acquire research funds that lack precisely because of the low quality level (Perkmann et al., 2013). In addition, while top universities have excellent research capacities, less prestigious institutions may well have a comparative advantage "at the stage where firms need to interact with university personnel who are willing to focus on their immediate problems and help them apply their knowledge" (Mansfield & Lee, 1996: 1057).

A similar adverse effect may come from the characteristics of evaluation exercises like the RAE. Given that the RAE scores are based on refereed publications, departments that are more oriented towards the production of publishable research may be advantaged and highly valued, while those that are more focused on teaching activity and/or engaged with industry may be valued less. As a consequence, academic departments dedicated to more abstract research (e.g. basic sciences) may further reduce their interest in pursuing academic engagement, while departments in applied sciences may end up increasing their interaction patterns at the expense of their research quality.[19]

Policy makers should acknowledge the possibility of adverse selection and consider whether it is a desirable outcome for the university system as well as for the whole economy. If not, appropriate measures aimed at counterbalancing such effect should be put in place, including the specific targeting of low quality institutions with the aim of both improving their research standing and providing additional funding for U–I interactions. Finally, and relatedly, we have shown that cumulated experience in U–I interaction appears to mitigate the negative relationship between research quality and academic engagement in basic sciences departments, hence influencing the extent of future interactions. Therefore, it is arguable that academia-business linkages not only have direct positive effects on public and private research, but they also have indirect effects because they are likely to boost future interactions in scientific domains where links with industry tend to be low. Both policy makers and technology transfer managers inside universities should take such indirect effect into account, as it may represent an additional reason for supporting low quality institutions to avoid adverse selection effects.

Appendix

See Tables 11, 12 and 13.

[19] We thank an anonymous reviewer for suggesting the possibility of an adverse effect of the RAE framework.

Table 11 Pairwise correlations among variables (*5% significance level) (N=280)

	IndFund	*TopQual*	*QualLevel_1*	*QualLevel_2*	*QualLevel_3*	*Basic*	*Applied*	*Experience*	*TotIndFund*	*PublFund*	*Size*	*Dist*
IndFund	1											
TopQual	0.2266*	1										
QualLevel_1	−0.2266*	−1	1									
QualLevel_2	0.0889	0.7537*	−0.7537*	1								
QualLevel_3	0.2018*	0.3826*	−0.3826*	−0.3188*	1							
Basic	0.0209	0.1934*	−0.1934*	0.1486*	0.07	1						
Applied	0.0537	−0.0827	0.0827	−0.081	−0.0055	−0.8504*	1					
Experience	0.5853*	0.2961*	−0.2961*	0.0048	0.4203*	−0.0483	0.11	1				
TotIndFund	0.2383*	0.0484	−0.0484	−0.0407	0.1270*	−0.1712*	0.1783*	0.3075*	1			
PublFund	0.0558	0.0988	−0.0988	0.067	0.0484	0.0597	−0.0488	0.1124	0.101	1		
Size	0.3756*	0.3528*	−0.3528*	0.0023	0.5056*	0.2704*	−0.1964*	0.5537*	0.2791*	0.2012*	1	
Dist	−0.0043	−0.0815	0.0815	0.0538	−0.1932*	0.0312	−0.0346	−0.0633	0.0191	−0.022	−0.112	1
Eastmid	0.0131	−0.1061	0.1061	−0.0233	−0.1203*	−0.0431	0.0075	−0.0394	0.0592	−0.0358	−0.0809	−0.1699*
Easteng	0.1688*	0.0357	−0.0357	−0.0908	0.1791*	0.0024	0.0341	0.2244*	0.1386*	0.1221*	0.3447*	−0.1187*
London	−0.0233	0.0905	−0.0905	0.0246	0.096	−0.0747	0.0936	−0.0184	−0.0255	0.1297*	−0.0248	−0.2242*
Noreast	0.0244	0.0083	−0.0083	0.0286	−0.0283	−0.0632	0.0914	0.024	0.079	0.0007	−0.0307	0.1467*
Norwes	−0.0615	−0.054	0.054	0.0034	−0.0828	0.0123	0.0075	−0.0394	−0.0575	−0.0341	−0.1228*	0.0165
Noirela	−0.0212	−0.0309	0.0309	0.0141	−0.0644	−0.0146	−0.0082	−0.0552	0.0423	−0.0089	0.009	0.2531*
Scotlan	0.0304	−0.0718	0.0718	0.0415	−0.1618*	0.048	−0.0686	−0.0366	−0.0747	−0.0235	−0.0484	0.6808*
Southea	0.0098	0.069	−0.069	−0.0475	0.1662*	0.0426	−0.0285	0.1135	−0.0711	−0.0507	0.1830*	−0.2319*
Southwe	−0.0818	−0.0412	0.0412	−0.0405	−0.0025	0.0218	−0.0303	−0.077	−0.0072	−0.0235	−0.0519	−0.0617
Wales	−0.0531	−0.0596	0.0596	−0.0256	−0.0499	0.0024	0.0017	−0.0794	−0.1248*	−0.0458	−0.0823	−0.0124
Westmid	0.0178	0.0417	−0.0417	0.0366	0.0086	0.0422	−0.0262	−0.0014	0.0361	−0.0067	−0.0166	−0.2119*
Yorkhum	−0.0072	0.0751	−0.0751	0.0576	0.0274	0.0035	−0.0446	−0.0124	0.0817	−0.0319	−0.0473	−0.0192

Table 11 (continued)

	Eastmid	*Easteng*	*London*	*Noreast*	*Norwes*	*Noirela*	*Scotlan*	*Southea*	*Southwe*	*Wales*	*Westmid*	*Yorkhum*
IndFund												
TopQual												
QualLevel_1												
QualLevel_2												
QualLevel_3												
Basic												
Applied												
Experience												
TotIndFund												
PublFund												
Size												
Dist												
Eastmid	1											
Easteng	−0.0712	1										
London	−0.1239*	−0.0985	1									
Noreast	−0.0605	−0.0481	−0.0838	1								
Norwes	−0.0895	−0.0712	−0.1239*	−0.0605	1							
Noirela	−0.0479	−0.0381	−0.0663	−0.0324	−0.0479	1						
Scotlan	−0.1203*	−0.0957	−0.1666*	−0.0813	−0.1203*	−0.0644	1					
Southea	−0.1112	−0.0884	−0.1540*	−0.0752	−0.1112	−0.0595	−0.1496*	1				
Southwe	−0.0874	−0.0695	−0.1209*	−0.0591	−0.0874	−0.0468	−0.1175*	−0.1086	1			
Wales	−0.0712	−0.0566	−0.0985	−0.0481	−0.0712	−0.0381	−0.0957	−0.0884	−0.0695	1		
Westmid	−0.083	−0.066	−0.1149	−0.0561	−0.083	−0.0444	−0.1116	−0.1031	−0.081	−0.066	1	
Yorkhum	−0.1036	−0.0824	−0.1435*	−0.0701	−0.1036	−0.0555	−0.1394*	−0.1288*	−0.1012	−0.0824	−0.0961	1

Table 12 OLS regressions Hp 1a and 1b, excluding academic departments in London area. Dep. Var.: IndFund

Variables	(1) *IndFund*	(2) *IndFund*	(3) *IndFund*	(4) *IndFund*
TopQual	0.691**	−0.568		
	(0.311)	(0.451)		
QualLevel_2			0.617**	−0.532
			(0.309)	(0.480)
QualLevel_3			1.029**	−0.631
			(0.448)	(0.542)
Basic	1.271**	1.003*	1.258**	1.014*
	(0.594)	(0.552)	(0.596)	(0.556)
Applied	0.691	0.371	0.668	0.375
	(0.547)	(0.579)	(0.548)	(0.582)
*TopQual*Basic*	−1.277**			
	(0.549)			
*TopQual*Applied*		1.373**		
		(0.535)		
*QualLevel_2*Basic*			−1.159*	
			(0.591)	
*QualLevel_3*Basic*			−1.666***	
			(0.637)	
*QualLevel_2*Applied*				1.268**
				(0.570)
*QualLevel_3*Applied*				1.700***
				(0.634)
Experience	0.679***	0.690***	0.660***	0.674***
	(0.129)	(0.127)	(0.138)	(0.136)
TotIndFund	0.0954	0.0960	0.0952	0.0959
	(0.0698)	(0.0691)	(0.0698)	(0.0693)
PublFund	0.0299	0.0317	0.0320	0.0332
	(0.0420)	(0.0414)	(0.0417)	(0.0412)
Size	0.323	0.297	0.315	0.295
	(0.283)	(0.279)	(0.285)	(0.282)
Dist	−0.184	−0.194	−0.177	−0.188
	(0.164)	(0.163)	(0.167)	(0.166)
Eastmid	0.234	0.271	0.286	0.311
	(0.514)	(0.509)	(0.532)	(0.524)
Easteng	0.216	0.230	0.230	0.243
	(0.414)	(0.407)	(0.415)	(0.407)
Noreast	0.0380	0.0459	0.120	0.115
	(0.583)	(0.575)	(0.605)	(0.594)
Norwest	−0.0175	−0.0164	0.0355	0.0279
	(0.502)	(0.493)	(0.512)	(0.503)
Noirela	0.500	0.486	0.547	0.525
	(0.500)	(0.499)	(0.502)	(0.500)

Table 12 (continued)

Variables	(1) *IndFund*	(2) *IndFund*	(3) *IndFund*	(4) *IndFund*
Scotlan	−0.298	−0.266	−0.256	−0.234
	(0.473)	(0.468)	(0.486)	(0.479)
Southea	−0.296	−0.306	−0.295	−0.303
	(0.571)	(0.563)	(0.574)	(0.566)
Southwe	0.356	0.408	0.391	0.435
	(0.444)	(0.453)	(0.440)	(0.447)
Wales	0.0172	0.0168	0.0537	0.0467
	(0.688)	(0.673)	(0.694)	(0.680)
Westmid	0.327	0.306	0.355	0.331
	(0.452)	(0.442)	(0.458)	(0.449)
Constant	0.922	1.136	1.130	1.284
	(1.343)	(1.345)	(1.406)	(1.406)
Observations	239	239	239	239
R-squared	0.393	0.397	0.395	0.398
Adj R-squared	0.340	0.344	0.336	0.339
F	8.627	9.077	12.67	12.58
Prob > F	0	0	0	0
LogLikelihood	−479.2	−478.5	−478.9	−478.2
LogLikelihood costant-only model	−538.8	−538.8	−538.8	−538.8

Robust standard errors in parentheses (***$p<0.01$, **$p<0.05$, *$p<0.1$)

QualLevel_1 and *Yorkhum* omitted because of collinearity

Table 13 OLS regressions Hp 2a and 2b, excluding academic departments in London area. Dep. Var.: IndFund

Variables	(1) Basic sciences *IndFund*	(2) Applied sciences *IndFund*	(3) Basic sciences *IndFund*	(4) Applied sciences *IndFund*
TopQual	−13.72***	−1.756		
	(5.115)	(2.727)		
QualLevel_2			−14.95***	−0.421
			(5.600)	(3.392)
QualLevel_3			−12.22**	−0.930
			(5.856)	(4.208)
Experience	0.330	0.447**	0.336	0.448**
	(0.318)	(0.219)	(0.320)	(0.220)
*TopQual*Experience*	0.902**	0.184		
	(0.344)	(0.187)		
*QualLevel_2*Experience*			0.991**	0.0869
			(0.378)	(0.232)
*QualLevel_3*Experience*			0.752*	0.151
			(0.387)	(0.279)
TotIndFund	0.123	0.0848	0.128	0.0875
	(0.118)	(0.0915)	(0.120)	(0.0932)
PublFund	0.108	0.0128	0.0969	0.0146
	(0.109)	(0.0488)	(0.109)	(0.0488)
Size	−0.0383	0.467	0.0670	0.452
	(0.331)	(0.511)	(0.312)	(0.504)
Dist	−0.582**	0.131	−0.620**	0.141
	(0.238)	(0.245)	(0.246)	(0.247)
Eastmid	−0.411	1.023*	−0.426	1.135**
	(0.828)	(0.558)	(0.821)	(0.572)
Easteng	0.243	0.220	0.695	0.226
	(0.993)	(0.453)	(1.047)	(0.487)
Noreast	0.485	−0.291	0.824	−0.181
	(1.133)	(0.667)	(1.497)	(0.704)
Norwest	0.726	−0.641	0.849	−0.555
	(1.084)	(0.538)	(1.116)	(0.557)
Noirela	2.309***	−0.586	2.303***	−0.481
	(0.858)	(0.551)	(0.859)	(0.579)
Scotlan	0.852	−0.797	0.920	−0.713
	(0.984)	(0.484)	(0.991)	(0.513)
Southea	0.405	−0.816	0.664	−0.827
	(0.909)	(0.787)	(0.949)	(0.855)
Southwe	0.820	0.0908	1.043	0.141
	(0.981)	(0.483)	(0.975)	(0.496)
Wales	−0.927	−0.0544	−0.921	0.00253
	(1.415)	(0.741)	(1.440)	(0.753)
Westmid	−0.257	0.312	−0.288	0.357
	(1.035)	(0.428)	(1.052)	(0.429)

Table 13 (continued)

Variables	(1) Basic sciences *IndFund*	(2) Applied sciences *IndFund*	(3) Basic sciences *IndFund*	(4) Applied sciences *IndFund*
Constant	9.201**	3.048	8.942**	2.898
	(4.200)	(2.328)	(4.147)	(2.353)
Observations	82	138	82	138
R-squared	0.524	0.458	0.533	0.462
Adj R-squared	0.397	0.382	0.390	0.375
F	7.571	12.20	8.742	14.74
Prob > F	0	0	0	0
LogLikelihood	− 161.8	− 260.6	− 160.9	− 260.1
LogLikelihood costant-only model	− 192.2	− 302.9	− 192.2	− 302.9

Robust standard errors in parentheses (***$p < 0.01$, **$p < 0.05$, *$p < 0.1$)

QualLevel_1 and *Yorkhum* omitted because of collinearity

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