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Sourcing insights elsewhere: The positive influence of academic engagement on scientific impact

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ABSTRACT

Multiple science policy initiatives in recent years have encouraged interaction between academic and non-academic actors as a way of aligning research priorities with societal challenges. Academic engagement, defined as scientists' knowledge-related interactions with non-academics, is recognised as crucial for promoting technological development and effectively addressing societal issues. However, whether such interactions stimulate or compromise fundamental scientific advances remains an open question. This paper contributes to the debate by exploring the extent to which academic engagement increases the production of cutting-edge research. We examine the relationship between scientists' interactions with non-academic actors and the production of high-impact research, using bibliometric indicators and primary data from a large-scale survey of scientists in all scientific fields affiliated with Spanish universities and public research organisations. Our results suggest an overall positive relationship between scientists' interaction with non-academic actors and the production of research findings with high scientific impact. We show, also, that this positive association is contingent on (i) the specific mode of interaction and (ii) the scientists' previous scientific achievements. We find that modes of interaction that facilitate knowledge exchange and cooperation are particularly conducive to the publication of cutting-edge research, compared to unidirectional forms of knowledge exchange, and that renowned and reputable scientists are the best positioned to leverage the opportunities offered by partnerships with non-academic actors.

1. Introduction

Designing and implementing initiatives to promote collaboration between academic scientists and non-academic actors is a central part of science policy (Harris et al., 2010; Hakkarainen et al., 2022). Over the years, universities and other research institutions have introduced a range of policy mechanisms designed to incentivise interaction between scientists and actors outside of academia, such as firms, hospitals and non-governmental organisations. These knowledge-related interactions are expected not only to contribute to the development of new technologies (Cohen et al., 2002; Mansfield, 1998) and address societal problems (Norström et al., 2020; Pohl et al., 2010; van der Hel, 2016) but also to increase science quality by leveraging the plurality of legitimate perspectives (Funtowicz and Ravetz, 1993; Wickson et al., 2006).

Despite these expectations, the relationship between interactions with non-academic actors and the advancement of scientific knowledge is subject to ongoing investigation (e.g., Banal-Estañol et al., 2015; Fini et al., 2022). While consensus about the positive effects of academic engagement on scientific productivity has grown, the influence on scientific impact and research quality is less clear. On the one hand, interaction with non-academic actors is believed to enrich research by exposing scientists to a plurality of perspectives and contexts that can inspire novel research questions and complement researchers' capacity to make fundamental scientific advances (Argote and Miron-Spektor, 2011; Dutrénit et al., 2010; Dolmans et al., 2021; Hakkarainen et al., 2022). On the other hand, these interactions can experience communication and coordination problems (Nasirov and Joshi, 2023), arising from the parties' distinct research priorities (Azoulay et al., 2011),

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differing timescales on project goals (Borah and Ellwood, 2022) and constraints on research time (Gulbrandsen and Smeby, 2005), which can limit the opportunities to make substantial contributions to science.

The objective of this study is to add to this open debate by addressing the following research question: whether and to what extent does academic engagement promote the generation of research results with high scientific impact? We aim to contribute to the university-society interactions literature in three ways. First, while existing studies focus predominantly on scientific productivity, we shift the emphasis to scientific impact. So far, very few studies examine scientific impact (Abramo et al., 2009; Bloch et al., 2019; Hottenrott and Lawson, 2017; Lebeau et al., 2008), and, notably, they provide mixed results. This lack of consensus stems from variations in the types of non-academic actors considered (although many studies focus exclusively on interactions with industry), modes of engagement, and the measures used to assess scientific impact. A shift in the focus from productivity to impact is particularly relevant since it highlights potential linkages between scientists' academic engagement and knowledge breakthroughs. Moreover, the reward system in science increasingly prioritises the visibility and relevance of research over the sheer quantity of knowledge produced (Hicks et al., 2015).

Second, we account explicitly for different modes of academic engagement, which contributes to the growing body of research aimed at understanding how diverse interaction modes influence scientific production (Callaert et al., 2015; Plantec et al., 2023; Tijssen, 2018). We propose that the relationship between scientists' academic engagement and their publication of cutting-edge research depends on the mode of interaction. Drawing on the literature on knowledge co-production (Hakkarainen et al., 2022) and university-industry linkages (D'Este et al., 2019), we distinguish explicitly between two types of interaction: joint research, which promotes knowledge exchanges through cooperation among the partners, and response mode, which centres largely on knowledge transfer mechanisms such as consultancies or contract research. While both interaction modes provide opportunities for learning and knowledge sharing, we posit that the former is more likely to trigger scientific novelty.

Third, we propose that the relationship between academic engagement and scientific impact is contingent on the scientists' accumulated experience in producing cutting-edge research. Specifically, we suggest that academics with a good scientific achievement track record, will be more likely to translate interactions with non-academic actors into high scientific impact research. We argue that this contingent effect is enabled by the cumulated advantage associated with the peer recognition system in science (Merton, 1968) and the capabilities built by renowned scientists to identify and develop original research ideas derived from interactions with non-academic actors (Ahmadi et al., 2022).

We test our propositions using data from a large-scale survey of 11,992 scientists, affiliated with a Spanish university or a public research organisation, from all fields of science. Our performance indicator, scientific impact, is based on scientists' publications included in the top 10% of most frequently cited papers (according to Web of Science). We employ Ordinary Least Square (OLS) regression analysis to show that scientists who collaborate actively with non-academic actors, generate more high-impact scientific contributions. We also find distinct associations for joint research and response mode with scientific impact. Finally, we find that an individual's good scientific achievement track record has a positive moderating effect on the relationship between scientists' academic engagement and the generation of high-impact research results.

The paper is structured as follows. Section 2 provides the conceptual background and develops the hypotheses. Section 3 discusses the data sources and describes the research method. Section 4 presents the findings. Finally, Section 5 discusses the findings, draws conclusions, and outlines the implications of our research, offering recommendations for policy.

2. Conceptual background

2.1. *Academic engagement and scientific impact*

2.1.1. *General antecedents*

We follow Perkmann et al. (2013) and Perkmann et al. (2021) and use the term 'academic engagement' to refer to 'knowledge-related interactions by academic researchers with non-academic organisations, as distinct from teaching and commercialisation' (Perkmann et al., 2021, p. 1). While commercialisation activities (e.g., licensing, spin-offs) tend to be infrequent events and generally involve the natural and engineering sciences, academic engagement is common to all scientific disciplines (Bekkers and Freitas, 2008; D'Este and Patel, 2007; Hughes and Kitson, 2012). The interaction can take various forms, including joint research, contract research, consulting and ad hoc advice.

While prior research has examined the influence on scientific productivity of scientists' interactions with non-academic actors, we would suggest that a focus on scientific impact rather than scientific productivity is important for both conceptual and empirical reasons. First, we contend that the benefits of academic engagement extend beyond direct outputs (e.g., publications and patents), and, potentially, result in more substantive indirect benefits. For instance, academic engagement can foster mutual learning among the collaborators, enhancing the originality and relevance of scientists' research work. Also, this type of engagement is likely to influence not only the specific research conducted in collaboration with non-academic actors but also the research portfolios of the scientists involved. Therefore, a scientific impact perspective allows deeper investigation of how such collaborations influence the trajectory and significance of scientists' knowledge production beyond the productivity metrics associated with the collaboration itself. Second, as Perkmann et al. (2021) point out, although there is increasing acknowledgement of the positive effects of academic engagement on scientific productivity, more empirical evidence is needed on the relationship between academic engagement and scientific impact: 'While by now we have evidence for a positive effect on the subsequent research productivity of academics, we have only tentative evidence on the effect of engagement on the quality of their publications, including whether the potential for breakthroughs increases' (p. 9).

Among the numerous conceptualisations of scholarly impact (e.g., Aguinis et al., 2012, 2014), we look specifically at the influence of scholars on the academic community, that is, we examine scientific impact. This impact can derive from multiple factors associated with the intrinsic merits of a particular piece of research, including its novelty, originality and relevance. Our focus on scientific impact is aimed at an investigation of the potential of academic engagement, as a form of knowledge co-production, to influence cutting edge scientific research. Much of the rationale for public spending on knowledge co-production and transdisciplinary research is based on the expectation that collaborative research modes contribute to both the extent of academic output and the production of original and impactful research (Reale et al., 2018). We expect that a focus on the production of original and influential research might reveal new mechanisms and provide an alternative perspective on the effect of academic engagement.

So far, the relationship between academic engagement and scientific impact has received scarce attention and the few scholarly findings on the topic are not conclusive. For instance, Bloch et al. (2019), drawing on papers co-authored by Danish academics and industry partners, identified a positive association between academic engagement and citation only for public-private partnerships involving at least one international partner. Another study, by Lebeau et al. (2008) in the Canadian context, found that national university-industry collaborations increase scientific impact based on citation counts, but this research is published in journals with lower impact factors. The study by Abramo et al. (2009) confirmed their results for the case of Italy; they found that while co-authored university-industry articles are not necessarily published in more prestigious journals, university researchers who collaborate with the private sector exhibit overall superior research performance[1] compared to colleagues who do not collaborate. However, the counter-narrative in Hottenrott and Lawson (2017) suggests that interaction with industry, proxied by industry-sponsored grants, eventually may compromise the development of high-impact research by potentially imposing greater time constraints and administrative burdens.

These different findings underline the need for increasing scrutiny. Also, most of the studies referred to above focus on co-authored publications resulting from collaborative research, and do not consider the broader influence of collaboration on researchers' performance beyond jointly authored papers. Several authors point out that co-publication only provides a marginal reflection of the multiple forms of engagement with non-academic actors (see Calvert and Patel, 2003; Lundberg et al., 2006; Yegros-Yegros et al., 2016). Thus, in the present study we adopt a broader perspective allowing a focus on the effects of engagement on the scientific impact of the engaged scientist' research output, not just on her co-authored publications. Overall, we concur with the concluding remarks to the systematic review conducted by Perkmann et al. (2021), which suggest that the current evidence on the relationship between academic engagement and scientific impact must be considered tentative. We try to fill some of the gaps in the existing research in order to further our understanding of the relationship between academic engagement and scientific impact.

2.1.2. The benefits of academic engagement for scientific impact

We propose that the academic engagement - scientific impact relationship is shaped by several factors. Scientists who engage with non-academic actors occupy a strategic brokerage position that enables them to tap into the best of both worlds (Kwon et al., 2020). Spanning institutional and organisational boundaries provides privileged access to non-redundant knowledge (Burt, 2004), allowing creative combinations of knowledge and original research topics (Arza, 2010; Beck et al., 2022; Gulbrandsen and Smeby, 2005). Also, interactions with non-academic partners often involve addressing problems that require creative solutions and 'outside the box thinking' (Tahamtan and Bornmann, 2018). In co-production processes, the plurality of expertise and viewpoints is important to inform decisions on research agenda setting, task distribution and implementation of research plans. It is precisely the heterogeneity of skills and perspectives enabled by co-production that promotes knowledge recombination and, ultimately, inspires more influential science (Uzzi et al., 2013).

We would argue, also, that another distinct added value of academic engagement are the information exchanges and insights facilitated by the dialogue between academics and non-academics. Regular bi-directional exchange of information and ideas can lead to production of cutting-edge research (Kou and Harvey, 2022; Romanova, 2022; Tsoukas, 2009). While quantitative examination would suggest that scientific knowledge resulting from academic engagement is due to partner specialisation (Bikard et al., 2019) and the opportunity to focus more on what each partner does best and what each of the institutions involved values the most, a qualitative view highlights the opportunities university interactions with non-academic partners provide for joint learning (Rossi et al., 2017). This resonates with research that shows that scientists' involvement in academic entrepreneurship shifts research attention towards new disciplines and research topics (Fini et al., 2022) and that scientists spanning distant research domains achieve greater visibility within the academic community (Leahey et al., 2017). We contend that the dialogic nature of interactions allows for greater awareness and understanding of each partner's distinct perspectives, which better equip scientists to address complex problems and conduct potentially more impactful research (Hakkarainen et al., 2022).

Finally, research collaborations with non-academic actors provide the academic partner with a deeper understanding of the practical contexts and specific needs of potential beneficiaries (Argote and Miron-Spektor, 2011; Dutrénit et al., 2010; Dolmans et al., 2021). For example, Bednarek et al. (2018) show that boundary-spanning researchers are more likely to identify opportunities for science to inform policy. They are better placed to exploit the scientific evidence and their knowledge of the context, to deliver more relevant and impactful results. Since academic engagement increases the focus on societal problems (De Silva et al., 2021) and on research that responds to the demands of the non-academic community, the research findings are likely to gain greater societal legitimacy (Llopis et al., 2022) and visibility (D'Este and Robinson-García, 2023).

The above arguments suggest an overall positive influence of academic engagement on scientific impact. Accordingly, we propose that scientists who engage actively with non-academic actors will produce research with higher scientific impact, compared to scientists who are not involved in, or display a low degree of, interactions with industry. We hypothesise that:

Hypothesis 1. There is a positive relationship between scientists' engagement with non-academic actors (academic engagement) and the scientific impact of their research.

2.2. Boundary conditions: past scientific achievements and modes of academic engagement

In this section, we examine two potential contingent factors involved in the relationship between academic engagement and scientific impact: scientists' past research achievements and the specific mechanisms of academic engagement.

2.2.1. Past scientific achievement

We argue that scientists with a track record of scientific achievement and significant reputation in the academic community will be better positioned to exploit the knowledge recombination opportunities derived from interaction with non-academic actors. First, the sociology of science literature refers to the cumulative advantage provided by scientific recognition. Merton (1968, 1988) proposed the idea of the Matthew effect in science, arguing that the advantage derived from peer recognition is a fundamental cause of social stratification in the scientific community: 'the accruing of large increments of peer recognition to scientists of great repute for particular contributions in contrast to the minimising or withholding of such recognition for scientists who have not yet made their mark' (Merton, 1988, p. 609). This effect also operates at the publication level (Price, 1976) and increases the inequalities in access to resources, career progress and learning opportunities (Merton, 1988). We argue that visibility and prior achievement, based on the number of highly cited published papers, provide the scientist with a preferential position within the opportunity structure of science, which allows better access to tangible and intangible resources. In turn, these different resources facilitate the identification of opportunities for knowledge recombination during interactions with non-academic actors and, potentially, result in highly original research.

Second, previous creative achievements are an important predictor of future creativity (Simonton, 1999). Already creative individuals are able to develop greater levels of creative self-efficacy (Tierney and Farmer, 2002), or belief in personal ability to be creative, given the prevailing resource constraints and context. A high level of creative self-efficacy increases the likelihood that a successful and prolific researcher will translate a given set of resources into novel outputs. For

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[1] Abramo et al. (2009) use the term *personal research performance* to refer to both higher output and fractional scientific strength (FSS), a metric that accounts for the quality of journals (measured by impact factor) and the individual's relative contribution (based on the inverse of the number of co-authors).

example, Karwowski and Beghetto (2019) suggest that experience of creative success boosts the individual's perception of 'creative agency' and the development of creative skills. Therefore, we suggest that scientists with a history of research achievements (e.g., publication of high-impact articles) will be better placed to benefit from the opportunities for joint learning offered by interactions with non-academic partners. A higher level of creative efficacy is likely to enhance the capacity to exploit the opportunities offered by interactions with non-academic actors and convert them into novel research ideas. In contrast, scientists with little or no experience in producing outstanding research will likely lack a frame of reference that allows the development of ideas emerging from interaction with non-academic actors into impactful research findings (Ahmadi et al., 2022).

Therefore, we suggest that scientists with a prior record of publishing cutting-edge research will be particularly well-positioned to leverage the opportunities offered by partnerships with non-academic actors. We argue that the positive relationship between academic engagement and scientific impact is likely to be stronger for scientists with a history of scientific achievement and hypothesise that:

Hypothesis 2. The positive relationship between scientists' engagement with non-academic actors and scientific impact is stronger for scientists with a track record of scientific achievements.

2.2.2. Forms of academic engagement: joint research versus response mode

Academic engagement includes multiple forms of interaction between scientists and non-academic partners. Work on the co-production of knowledge (Hakkarainen et al., 2022) and university-industry interaction (D'Este et al., 2019; Perkmann and Walsh, 2008) suggests that the form adopted depends strongly on the level of involvement of the non-academic partner. For example, consultancy services tend to involve unidirectional transfers of knowledge from the academic informant to the non-academic actor (De Silva and Rossi, 2018). While these interactions may provide learning opportunities and the sharing of practical know-how, they are less likely than other types of interaction to trigger significant novelty. However, in joint research between academic scientists and non-academic partners, sustained knowledge exchanges may provide opportunities for knowledge co-creation and cross-learning (De Silva et al., 2023). Thus, we suggest that, for the scientists, the opportunities for involvement in frontier research will differ depending on the form of the interaction.

We consider two frequent types of academic engagement: joint research and response-mode interactions (D'Este et al., 2019). We provide a characterisation of these two types of academic engagement that is deliberately stylized, acknowledging that, in practice, the boundaries between these two types might be often blurred. Joint research is a recognised formal R&D cooperation (Hall et al., 2001; D'Este et al., 2019; Perkmann and Walsh, 2008), characterised by a shared framing and definition of research objectives and a strong emphasis on interactive learning in all the research process phases (e.g., setting research priorities; development of materials and methods; data collection, processing and analysis; and interpretation, discussion and dissemination of results) (Perkmann and Walsh, 2008; Franzoni et al., 2022). We conceptualise joint research as a form of collaboration in which scientists and non-academic actors work together, with active involvement in most or all aspects of the research process.

Response-mode interactions include contract research and consultancy where, typically, the non-academic partner establishes the terms, research goals and time schedules in a formal contract (Schartinger et al., 2002). The research is commissioned by the non-academic partner and tends to involve more applied and short-term research than joint research arrangements (Van Looy et al., 2006). Contract research and consulting are demand-pull activities, in which the scientist responds to a specific need expressed by the non-academic actor, thus leading to a flow of knowledge that is mostly unidirectional. These types of interactions aim to solve practical problems and generally involve technical expertise (Manjarrés-Henríquez et al., 2009). Consulting activities generally take the form of advice rather than original research (Perkmann and Walsh, 2008). Some studies provide evidence of a trade-off between scientific and industrial relevance (Lam and de Campos, 2015): knowledge generated through response-mode interactions might be valuable for the industry partner, but unlikely to involve frontier science. For instance, Blandinieres and Pellens (2021) show that industry-pull-type collaborations are associated with a lower likelihood of research that triggers scientific debate. Thus, engagement in response-mode interaction might shift the scientist's focus away from current scientific problems and debates towards the transfer of knowledge and technology, and result in less visible or relevant scientific output.

In contrast, the bi-directional flows of knowledge that occur in joint research are likely to result in diverse ideas, perspectives and questions (Uzzi and Spiro, 2005) relevant to both the academic and non-academic actors (Murray and Stern, 2007). Joint research is likely to mobilise the different partners' knowledge and expertise and increase knowledge sharing. The knowledge exchange mechanisms and learning opportunities enabled can result in high-impact science. Therefore, we hypothesise:

Hypothesis 3. The positive relationship between scientists' engagement with non-academic actors and scientific impact is stronger in the case of joint research than response-mode interactions.

3. Data and method

3.1. Context

Our context is the public research system in Spain. Spain is interesting in that its particular institutional setting and science policy initiatives have aimed at fostering academic engagement for several decades. Still, Spanish scientists' engagement with non-academic actors is below the European average, as shown, for instance, by the share of university-private co-publications (lower in Spain than in Italy, France or the UK), and by Spanish companies being less prone to cooperate with higher education and research institutions (OECD, 2019).

A critical aspect of the Spanish science policy context is its Technology Transfer Offices (TTOs),[2] interface structures established in the late 1980s and present in all Spanish universities to promote interactions with business and facilitate innovation and technology transfer. The university TTO is the primary point of contact for academics seeking to establish contractual arrangements with companies and provide advisory or consulting services (Lafuente and Berbegal-Mirabent, 2019; García-Aracil et al., 2017). TTO staff offer institutional support to researchers involved in university-based spin-offs, licensing contracts, collaborative and contract research and/or patent applications and evaluate the quality of inventions disclosed by researchers (Caldera and Debande, 2010). Network of Spanish TTOs annual reports[3] show that the share of university funding allocated to TTOs has increased over recent years, and the Spanish Science, Technology and Innovation strategy for 2021–2027 stresses the importance of supporting these knowledge transfer channels.

Moreover, for more than a decade in Spain, national evaluation frameworks have tried to integrate knowledge transfer activities into their research assessment criteria, although the results have been mixed.

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[2] The 984/2022 Royal Decree related to the Spanish Ministry of Science and Innovation proposed that TTOs should be renamed Knowledge Transfer Offices (KTOs) and be part of an official registry.

[3] http://www.redotriuniversidades.net/.

Table 1

Population surveyed, responses and response rate by scientific discipline. [a]

	Population surveyed	Total responses	Response rate (%)	Final sample	Final sample response rate (%)
Biological Sciences	7270	1656	22.8	1515	20.8
Chemistry & Physics	8443	1966	23.3	1811	21.4
Earth & Environ. Sc.	5102	1174	23.0	1063	20.8
Engineering	4805	956	19.9	870	18.1
Humanities	2651	775	29.2	535	20.2
Maths & Computer Sc.	4958	919	18.5	847	17.1
Medical Sciences	11,203	1909	17.0	1657	14.8
Social Sciences	5476	1222	22.3	1011	18.5
Other Disciplines [b]	7498	1415	18.9	1208	16.1
Total	*57,406*	*11,992*	*20.9*	*10,517*	*18.3*

[a] This breakdown by discipline is based on WoS subject categories for the papers published by the target population during the period 2012 to 2014.

[b] This includes researchers with the same number of publications in two or more disciplines during the period 2012 to 2014. Since these scientists could not be assigned to a specific discipline based on the WoS categories, we classified them as 'other disciplines'.

In 2010, the nationwide *sexenio*, which assesses individual research productivity,[4] was extended to include a category related to knowledge transfer and knowledge exchange (Giménez-Toledo et al., 2023). Knowledge transfer and knowledge exchange are defined, broadly, to include participation in knowledge-based companies, licences/patents and other forms of intellectual property protection, R&D contracts with companies, publications derived from collaboration with socio-economic agents and contributions to industrial or commercial standards (Giménez-Toledo et al., 2023). However, in 2017, the whole initiative was discontinued. In 2018, the National Agency for Quality Assessment and Accreditation (ANECA) piloted a knowledge transfer and innovation *sexenio* scheme called the *transfer sexenio*. This was aimed at assessing researchers' engagement in knowledge transfer and innovation activities and has been seen as the first successful evaluation of individual knowledge transfer efforts in Spain (Giménez-Toledo et al., 2023). It remains to be seen whether this initiative will be fully adopted for subsequent research evaluation cycles. Thus, both the prioritisation of support mechanisms, such as the TTO/KTOs, and experimental reforms to the Spanish research assessment framework, signal ongoing efforts by the Spanish scientific system to reconcile research excellence with societal relevance and boost engagement between academic and non-academic actors.

3.2. Data

The study uses primary and secondary data matched at the individual level. The primary data come from responses to a unique survey of scientists in the Spanish public research system, administered in 2016. The target population was active scientists affiliated to a Spanish university or public research organisation. In the absence of an official public register, the reference population was constituted of scientific authors with a Spanish institutional affiliation who had at least one published article in a scientific journal indexed in the Web of Science (WoS) database during the period 2012–2014 inclusive. This resulted in a sample of 57,406 scientists[5] who were invited to participate in the survey. The questionnaire was administered online in June and July 2016. Participants received a personal link to the online survey and were sent reminders two and four weeks after the initial invitation to participate. We received 11,992 valid responses, a response rate of 21% (see Table 1). The respondents cover all fields of science, including engineering and physical sciences, biology and medicine, and social sciences and humanities. The respondents are largely representative of the target population in terms of scientific disciplinary distribution since almost all response rates range between 19% and 23% for total responses and between 16% and 20% for the final sample (see Table 1).[6]

The data collected by the online questionnaire covered different aspects of scientists' engagement with non-academic actors, including modes and frequency of interaction.[7] The questionnaire was designed based on a focused review of the literature and scales validated in previous work. It was refined and endorsed through interviews and meetings with researchers at public universities, public research centres and university hospitals.[8]

We also collected publication and citation records to obtain information on scientific performance. Our bibliometric data are from WoS and include the total number of publications and the number of citations to each publication. Our final sample, based on the number of observations with data for all our variables of interest, is 10,517 (see Table 1).[9]

3.3. Method

3.3.1. Key variables

Dependent variable. Our dependent variable *(scientific impact)* captures the number of high scientific impact publications for each scientist in our sample. To construct this variable, for each scientist, we considered the articles published in journals listed in WoS during the period 2013–2015; we then collected the citations to these articles, from the year of publication up to 2020. We employed a percentile-based approach (e.g., Aagaard et al., 2015), to compare the citation profile of each publication with all the articles published worldwide, in the same year, the same research field and classed as the same document type (i.e., articles and review articles). This normalisation is important

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[4] The *sexenio* assessment evaluates 5 contributions—mostly scientific papers—submitted by researcher applicants, produced over a 6-year period. Up to 2009, the types of contributions accepted for the *research sexenio* included scientific publications (articles, book chapters, books) and technological results (patents and other intellectual property).

[5] The starting population was 64,508 scientists. However, in some cases (4059 cases), email addresses (obtained from publications records) were outdated or invalid at the time of the survey; in other cases (some 3043), the researcher's affiliation was to a type of organisation not included in our selection criteria (e.g., a private university) or the invitation to participate in the survey was returned because the researcher had retired or was no longer employed by the organisation reported on the article. This led to a population of 57,406 scientists.

[6] We conducted wave analysis to ensure that our data did not suffer from significant sampling bias. The underlying assumption in wave analysis is that late respondents are representative of non-respondents (Armstrong and Overton, 1977). Specifically, we created two respondent categories ('early respondents' and 'late respondents'), based on survey response dates. We conducted a *t*-test to compare the mean values of our key variables across both groups. For the majority of our variables, we found no significant differences.

[7] Appendix B provides a list of the survey questions relevant to this study.

[8] The full questionnaire is available on request.

[9] The reduced number of observations was due to failure to match the survey data to our secondary data on publications and, also, to missing information for some key variables in the survey responses which resulted in these responses being dropped.

to correct for differences in citation profiles among disciplines and publication years. A paper is deemed to have high impact if it is within the top 10% most frequently cited papers in its comparison group. Compared to indicators based on averages, percentile-based approaches are less vulnerable to extreme values, which tend to characterise citation counts (Waltman et al., 2011). Our indicator choice is in line with bibliometrics research which shows that percentile-based citation-counts indicators are reliable proxies for research impact (Veugelers and Wang, 2019; Wagner et al., 2019).

Since a publication might belong to more than one field, the indicator is fractionally weighted for each field. For instance, if a paper is classified in two different fields, but is in the top 10% of most frequently cited papers in only one of these fields, the indicator takes the value 0.5 (i.e., fractional count, Waltman et al., 2011). This field-level normalisation helps to account for the interdisciplinarity of some of the articles. We aggregated these article-level indicators at the author-level, by summing the scores for all the top 10% most frequently cited papers published by the individual scientist in the period 2013–2015. The method of summing paper-level bibliometric indicators to create higher-level aggregates is well-established in the literature (Wagner et al., 2022; Wildgaard et al., 2014). Thus, our percentile-based indicator of scientific impact measures the total number of papers published by the individual scientist included in the top 10% of the most frequently cited papers. Finally, the variable was log-transformed to address the skewed distribution typical of publications data.

Independent and moderating variables. The independent variables associated with a scientist's *academic engagement* were built using the survey data. The questionnaire asked respondents to indicate the mechanism(s) and frequency of interactions with different types of non-academic actors, such as Small and Medium-sized Enterprises (SMEs), large firms, public administrations, non-governmental organisations, etc.[10] The question posed was: 'During the period 2013–15, please indicate how many times you engaged in the following formal interactions related to your scientific activity'. Respondents were given a list of formal interactions associated with each of the different non-academic actor types and were asked to report the interaction frequency - 0 times, 1–2 times, 3–5 times, 6–9 times, 10 or more times.[11]

We built our *academic engagement* variable by computing the frequency of respondents' engagement in a range of formal interactions, including joint research and consulting or contract research, and considering all types of non-academic organisations. We operationalised *joint research* as the frequency of each respondent's involvement in joint (active involvement of both partners) research projects, employing a variable based on the sum of the frequency of interaction with each non-academic partner. We constructed an indicator of *response mode* to measure the frequency of the respondent's involvement in consulting (i.e., technical or advisory services) and contract research (i.e., research partly or fully commissioned by the non-academic partner). Again, we summed the interaction frequencies for these two types of collaboration with each non-academic partner involved in a consulting agreement or contract research. The final scores were log-transformed to address the highly skewed nature of the three independent variables (*academic engagement*, *joint research* and *response mode*).

Past scientific achievement is measured by an indicator of the cumulative number of highly cited papers at the individual level. For each respondent, we identified the total number of highly cited articles published in WoS-indexed journals since the date of the scientist's first recorded publication up to 2013 (highly cited papers are those within the top 10% most frequently cited papers in its comparison group). This indicator proxies for accumulated peer recognition of the scientist's contribution to science. The variable was log-transformed to address distribution skewness.

Control variables. We included individual and contextual-related variables to account for other factors that might influence scientific impact.

Individual attributes. First, since the scientist's past scientific productivity is likely to influence current scientific impact, we controlled for the cumulative number of published papers up to 2015 (*Cumulative papers*) to capture the scientist's overall productivity, including during the focal period 2013–2015.[12] We controlled, also, for the scientist's *age* and *gender* and included four dummies (*Assistant Professor, Associate Professor*, *Full Professor*, *Other*) for the scientist's *academic rank*. In all the regression models, Associate Professor (the most populated category) is the reference category. We controlled for the percentage of time spent on research-related duties; specifically, we asked respondents to indicate, on a 0–100 scale, how much of their working time during a normal working week was devoted to research activities. We also controlled for engagement in other types of interaction (*Other interaction modes*) that might influence their performance.[13] Finally, we controlled for previous non-academic experience (*non-academic exp.*), that is, how long (in years) respondents had worked in a non-academic institution before joining academia, and for the scientist's research orientation, measured as the degree of applied (versus basic) research (*Applied orientation*) on a scale ranging from 0 (basic) to 100 (applied).

Contextual factors. Since some studies suggest that larger teams produce more highly cited papers, we controlled for research *team size*, measured as the number of scientists in the academic research team (as reported in the survey) (Wuchty et al., 2007). Also, since there is a link between interdisciplinarity and research impact (Leahey et al., 2017; Fontana et al., 2022), we controlled for research team interdisciplinarity (*Team interdiscipl.*) by asking respondents to indicate the number of distinct disciplinary backgrounds covered by the research team members. We included four dummies to control for the type of institution to which the respondent was affiliated (*university*, *public research organisation, hospital, hybrid affiliation*). Since a university affiliation accounts for the largest group, in the analysis, we use university as the reference category. Since our sample includes scientists from various fields, we included nine dummies for scientific specialisation (*Scientific fields*). Finally, we controlled for location of the institution of affiliation, using 18[14] regional-level dummies (*Regions*).

3.3.2. *Empirical model*

OLS regression was employed to examine the relationship between academic engagement and scientific impact. As already mentioned, we log-transformed the original variables for scientific impact and academic engagement to account for their highly skewed distribution (see

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[10] The survey distinguished among SMEs, large firms, public administrations, private non-profit institutions (e.g., foundations), non-governmental organisations, hospitals, associations (e.g. professional, patient and citizen associations) and international institutions (e.g., World Bank, UNESCO).

[11] To analyse the frequency of interactions, we transformed the categorical data into continuous measures. We recoded the frequency of each categorical variable to its corresponding midpoint value. E.g., '3–5 times' was replaced by 4 and '6–9 times' was replaced by 7.5. We summed the recoded values across all relevant interaction forms to obtain a continuous measure of interaction frequency.

[12] To avoid overlap with our dependent variable (*scientific impact*), it excludes the count of highly cited papers published in the period 2013–2015. It was also log-transformed to mitigate skewness.

[13] The other interaction modes included: (1) providing specialised training; (2) temporary stays at a non-academic organisation; (3) hosting non-academic actors; (4) to work on creative or cultural products; (5) to work on guidelines, protocols or norms; (6) renting equipment or materials to non-academic partners; and (7) testing (e.g., proof of concept, prototypes). Table 2 presents the relevant variable which is included in the regression model as 'other interaction modes'.

[14] In terms of location, we are distinguishing between the 17 autonomous communities and the autonomous city of Ceuta.

Table 2
Descriptives (N = 10.517).

	Mean	Std. Dev.	Median	Min	Max
Scientific impact	0.86	3.26	0.00	0	101
Academic engagement	7.50	14.24	1.50	0	210
Joint research	2.35	4.98	0.00	0	70
Response mode	5.15	10.06	1.50	0	140
Past scientific achievement	2.57	6.81	0.33	0	315
Cumulative papers	27.99	40.75	14.87	0	750
Age	49.12	10.07	49.00	23	83
Gender = Female	0.36	0.48	0.00	0	1
Time for research	44.39	19.72	40.00	0	100
Non-academic exp.	1.93	4.32	0.00	0	41
Applied orientation	50.88	32.96	50.00	0	100
Team size	6.39	4.10	5.00	1	21
Team interdiscip.	2.50	1.78	2.00	1	27
Other interaction modes	7.23	18.31	0.00	0	396
University	0.74	0.44	1.00	0	1
Research centre	0.16	0.37	0.00	0	1
Hospital	0.05	0.23	0.00	0	1
Hybrid centre	0.04	0.20	0.00	0	1
Full prof.	0.18	0.38	0.00	0	1
Associated prof.	0.54	0.50	1.00	0	1
Assistant prof.	0.13	0.34	0.00	0	1
Other positions	0.15	0.35	0.00	0	1

Notes: In order to provide more meaningful information, the descriptive statistics refer to the original (non-transformed) variables. The dummies for scientific field and region are not displayed here.

Table 2). To address potential heteroscedasticity issues, we used robust standard errors. Because our continuous independent and control variables are measured on different scales, they were standardised before inclusion in the regression model. Our baseline regression model, which tests Hypothesis 1, is:

$$sc\_impact_i = \beta_0 + \beta_1 * \ academic\ engagement_i + \beta_3 * C_i + \epsilon_i \qquad (1)$$

where *sc_impact* is the fractional number of publications of scientist *i* corresponding to the top 10% most highly cited publications in the respective scientific field. The independent variable in our model refers to our overall measure of academic engagement. To test Hypothesis 2, we computed the interaction term between *academic engagement* and *past scientific achievement*. To test Hypothesis 3, we split *academic engagement* into *joint research* and *response mode*. All the specifications include the full list of control variables (C), described in Section 3.3.1. Appendix Table A1 provides a comprehensive summary of all the variables used in the study.

4. Results

4.1. Descriptive statistics

Table 2 presents the descriptive statistics of all our variables, including the mean, standard deviation, median, minimum and maximum. Concerning *scientific impact*, 41% of the scientists in our sample had published at least one paper, between 2013 and 2015, that was included in the top 10% most frequently cited papers; the average number of top-cited papers per scientist is 0.86. For *academic engagement*, 57% of respondents reported having participated in some form of engagement with a non-academic actor, with an average of 7.5 such interactions in the period 2013–2015. For interaction mode, 41% of respondents had participated at least once in joint research and 52% had engaged in response-mode activities (see Table 3). The respective mean values for frequency of engagement in joint research and response mode are 2.35 and 5.15, indicating twice as frequent engagement in response-mode activities (i.e., contract research and consultancy) than in joint research (Table 2).

Fig. 1 depicts the percentage of our sample respondents who engaged at least once in joint research, response mode and in both modes (joint research and response mode), broken down by respondent scientific field. As expected, respondents working in more applied fields, such as engineering and medical sciences, tend to collaborate with non-academic actors more often than respondents working in chemistry, physics and humanities. Overall, response-mode interactions are more common than joint research, indicating a preference or greater opportunity for these types of engagements. We observe, also, that a significant proportion of scientists engage simultaneously in both modes. Appendix Table A2 presents the correlation matrix for our variables and shows a high pairwise correlation between joint research and response mode (0.76, $p < 0.05$), suggesting that those scientists who engage with non-academic actors tend to participate in multiple types of interactions simultaneously.

Our data reveal that, typically, scientists also engage with several different non-academic actor types. Among the scientists who engage in interactions (including “other interaction modes”) with non-academic actors (i.e., 6201 out of 10,517), 56% (i.e., 3474 scientists) had interacted with more than one type of non-academic actor compared to 44% (2727 scientists) who had interacted with only one type of non-academic actor. Table 3 shows the percentage of our sample respondents who engaged at least once with non-academic actors, broken down by type of actor and interaction mode. The data indicate that interaction with an industry actor predominates for all interaction modes. Specifically, 25% of scientists (2652 out of 10,517) had collaborated with industry in joint research, and 35% had engaged in response mode. The next most frequent category is interaction with government, ranging from 17% (joint research) to 23% (response mode). We observe a moderate level of engagement with non-profit organisations and a low level of engagement with ‘Others’. The relative importance of each type of non-academic actor is consistent across all interaction modes (industry > government > non-profit > other). In terms of interaction intensity, again, this appears to be relatively consistent across different types of non-academic actors. This consistency suggests that the interaction profile by type of non-academic actor is similar, regardless of the type of engagement: joint research or response mode.

4.2. Hypotheses testing

Tables 4 and 5 present the results of the statistical analysis. Table 4 relates to Hypotheses 1 and 2. Model 1 (Table 4) is the baseline model and includes only the control variables. We found that among individual factors, scientist age has a negative and statistically significant effect on the dependent variable and devoting time to research has a positive influence on scientific impact. Also, as expected, prior academic performance has a positive influence on the number of the scientist’s high-impact papers. This is shown by the positive and significant coefficients of *past scientific achievement* and *cumulative papers*. Other individual factors, such as professional experience outside academia, also display a positive and significant influence on scientific impact. At the research team level, scientists working in larger and more interdisciplinary teams publish more high-impact papers. Compared to university-affiliated scientists, those working in hospitals, research centres and hybrid centres achieve higher scientific impact, which points to the influence of the institutional setting.

Model 2 builds on the previous specification and includes *academic engagement*. The estimated results show a positive and statistically significant association between academic engagement and publishing highly cited articles: $\beta = 0.018$, *p*-value <0.05. We find that, all other factors remaining constant, a 1 standard deviation increase in academic engagement increases the fractional count of highly cited papers by approximately 1.8%. This supports Hypothesis 1. Given their log-transformation and standardisation, determining the magnitude of these coefficients can be difficult. However, standardisation allows direct comparison of the coefficients. For example, academic engagement, with a coefficient of 0.018, has an influence on the number of high-impact papers that is quantitatively similar to the effect of

Table 3
Number (N) and percentage (%) of respondents who interacted at least once, by type of non-academic actor and interaction mode (N = 10,517).

	Academic engagement		Joint research		Response Mode		Other inter. Modes	
	N	%	N	%	N	%	N	%
Industry	4029	38.31	2652	25.22	3699	35.17	2916	27.73
Government	2798	26.60	1738	16.53	2453	23.32	2007	19.08
Non-profit	1714	16.30	1023	9.73	1476	14.03	1357	12.90
Others	1218	11.58	1021	9.71	796	7.57	972	9.24
All types of non-academic actors	6025	57.3	4291	40.8	5443	51.8	4790	45.6

Notes: Industry: SMEs and large firms; Non-profit organisations: associations and private non-profit organisations; Government: government departments, international institutions; Other: hospitals, other institution types. The 5th row shows the figures for overall engagement in each mode, regardless of the type of non-academic actor.

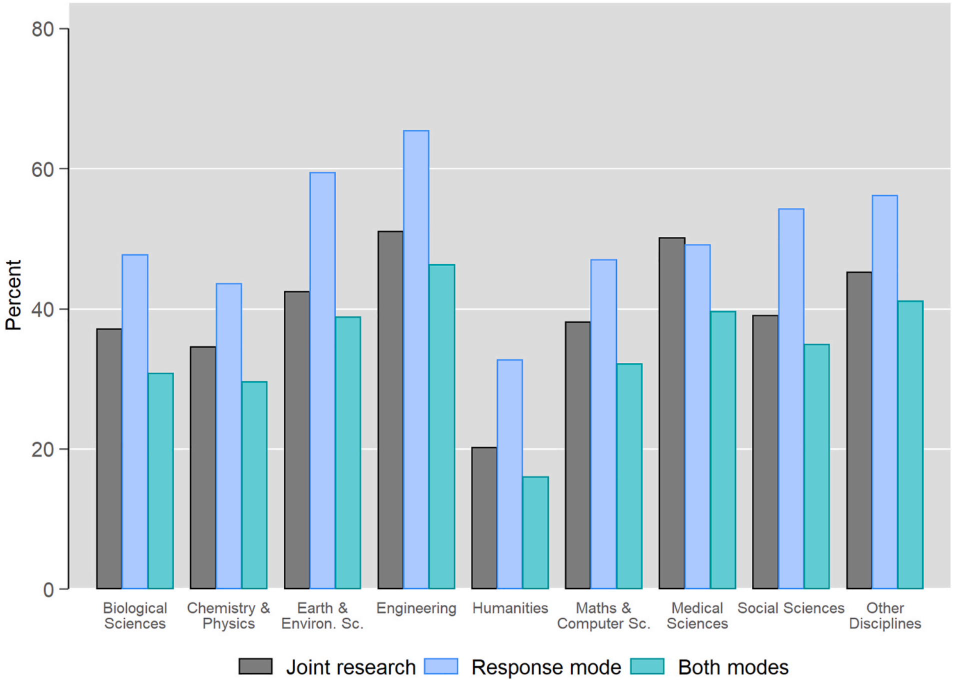

Fig. 1. Percentage of respondents who engaged in different interaction modes with non-academic actors, by scientific field.

dedicating time to research activities – with a coefficient of 0.022. This impact is significantly greater than the coefficient of applied orientation (0.018 vs 0.012) and is mostly higher than the estimates for field-level effects. This highlights the strong association between academic engagement and scientific impact. Model 3 shows that the interaction between academic engagement and past scientific achievement is positive and statistically significant. This supports Hypothesis 2 that higher levels of accumulated peer recognition have a positive moderating effect on the relationship between scientist's academic engagement and generation of high-impact research results.

To further check the magnitude of the interaction effect, we calculated the predicted values of our dependent variable, *scientific impact*, across different levels of academic engagement and past scientific achievement. In Fig. 2, the interaction effect is represented by slopes of the lines reflecting different levels of past scientific achievement. For scientists with high levels of past scientific achievement, the slope is notably steeper, indicating a stronger positive relationship between academic engagement and predicted scientific impact. For those with average past scientific achievement, the slope remains positive but is less steep compared to that of high achievers. For scientists with low past scientific achievement, the slope is slightly decreasing, suggesting that, for this group, academic engagement has a minimal negative effect on the predicted scientific impact. Also, the non-overlapping confidence intervals (the vertical bars) between the high and low past achievement lines, especially at higher levels of academic engagement, confirm that these differences are statistically significant.

Table 5 presents the results for the two modes of academic engagement analysed. In Model 4, the main independent variable is *joint research,* which has a positive and significant coefficient ($\beta = 0.019$, *p*-value <0.01), suggesting that scientists participating in joint research with non-academic partners publish more highly cited papers. Specifically, we found that a 1 standard deviation increase in joint research activities with non-academic actors increased the fractional count of highly cited papers by approximately 1.9%. In Model 5 (*response mode*), there is no evidence of a statistically significant association between engagement in consulting and/or contract research and the number of highly cited papers ($\beta = 0.011$, *p*-value >0.10). These results hold if we include joint research and response mode in the same model (Model 6). This supports Hypothesis 3 that engagement in *joint research* is more strongly associated with high scientific impact research compared to engagement through *response-mode* mechanisms.

Our analysis shows that joint research and response-mode activities result in distinctly different outcomes, with the former being positively associated with scientific impact. This distinction underscores the different features of interaction types. While analysis of the distinct nature and objectives of interaction is beyond the scope of the present study, our results confirm our expectations that: bi-directional flows of knowledge between the diverse partners involved in collaborative

Table 4
Academic engagement and scientific impact. OLS regressions.

	M1: Controls			M2: Academic engagement			M3: Moderation		
	Coef.	SE	*p*-value	Coef.	SE	*p*-value	Coef.	SE	*p*-value
Academic engagement				0.018	(0.008)	0.017	0.016	(0.007)	0.033
Past scientific achievement*Acad. Engag.							0.026	(0.006)	0.000
Past scientific achievement	0.309	(0.008)	0.000	0.309	(0.008)	0.000	0.304	(0.008)	0.000
Cumulative papers	0.072	(0.008)	0.000	0.071	(0.008)	0.000	0.070	(0.008)	0.000
Age	−0.097	(0.006)	0.000	−0.097	(0.006)	0.000	−0.096	(0.006)	0.000
Gender = Female	−0.011	(0.009)	0.225	−0.010	(0.009)	0.304	−0.011	(0.009)	0.231
Time for research	0.022	(0.005)	0.000	0.022	(0.005)	0.000	0.023	(0.005)	0.000
Non-academic exp.	0.017	(0.005)	0.000	0.017	(0.005)	0.000	0.017	(0.005)	0.000
Applied orientation	0.015	(0.005)	0.003	0.012	(0.005)	0.015	0.012	(0.005)	0.023
Research centre	0.040	(0.026)	0.014	0.040	(0.026)	0.013	0.041	(0.026)	0.011
Hospital	0.067	(0.030)	0.010	0.070	(0.030)	0.007	0.071	(0.030)	0.007
Hybrid centre	0.110	(0.032)	0.000	0.112	(0.032)	0.000	0.109	(0.032)	0.000
Team size	0.041	(0.005)	0.000	0.040	(0.005)	0.000	0.039	(0.005)	0.000
Team interdiscip.	0.013	(0.005)	0.017	0.012	(0.005)	0.019	0.013	(0.005)	0.017
Other inter. Modes	0.011	(0.005)	0.028	−0.002	(0.007)	0.749	−0.001	(0.008)	0.888
Constant	0.264	(0.032)	0.000	0.265	(0.032)	0.000	0.264	(0.032)	0.000
Scientific field (9)	Yes			Yes			Yes		
Regions (18)	Yes			Yes			Yes		
Academic rank (4)	Yes			Yes			Yes		
N	10,517			10,517			10,517		
R^2	0.375			0.375			0.377		
R^2_adj	0.372			0.373			0.375		

Notes: Robust standard errors. All continuous independent and control variables are standardised. The dependent variable is the natural logarithm of the total number of papers published in the period 2013–2015 included in the top 10% most frequently cited: ln (n° highly cited papers + 1).

Table 5
Joint research/Response mode and scientific impact. OLS regressions.

	M4: Joint research			M5: Response mode			M6: Full model		
	Coef.	SE	*p*-value	Coef.	SE	*p*-value	Coef.	SE	*p*-value
Joint research	0.019	(0.007)	0.004				0.018	(0.007)	0.012
Response mode				0.011	(0.007)	0.107	0.006	(0.007)	0.440
Past scientific achievement	0.309	(0.008)	0.000	0.309	(0.008)	0.000	0.309	(0.008)	0.000
Cumulative papers	0.071	(0.008)	0.000	0.071	(0.008)	0.000	0.071	(0.008)	0.000
Age	−0.096	(0.006)	0.000	−0.097	(0.006)	0.000	−0.096	(0.006)	0.000
Gender = Female	−0.011	(0.009)	0.240	−0.010	(0.009)	0.285	−0.010	(0.009)	0.271
Time for research	0.022	(0.005)	0.000	0.022	(0.005)	0.000	0.022	(0.005)	0.000
Non-academic exp.	0.017	(0.005)	0.000	0.017	(0.005)	0.000	0.017	(0.005)	0.000
Applied orientation	0.013	(0.005)	0.008	0.013	(0.005)	0.009	0.013	(0.005)	0.013
Research centre	0.040	(0.026)	0.014	0.040	(0.026)	0.013	0.040	(0.026)	0.014
Hospital	0.068	(0.030)	0.009	0.070	(0.030)	0.008	0.070	(0.030)	0.008
Hybrid centre	0.110	(0.032)	0.000	0.111	(0.032)	0.000	0.111	(0.032)	0.000
Team size	0.040	(0.005)	0.000	0.041	(0.005)	0.000	0.040	(0.005)	0.000
Team interdiscip.	0.012	(0.005)	0.021	0.013	(0.005)	0.018	0.012	(0.005)	0.022
Other interaction modes	−0.003	(0.007)	0.701	0.003	(0.007)	0.652	−0.005	(0.008)	0.482
Constant	0.265	(0.031)	0.000	0.265	(0.031)	0.000	0.265	(0.031)	0.000
Scientific field (9)	Yes			Yes			Yes		
Regions (18)	Yes			Yes			Yes		
Academic rank (4)	Yes			Yes			Yes		
N	10,517			10,517			10,517		
R^2_adj	0.375			0.375			0.375		
R^2	0.373			0.372			0.373		

research projects, increase the quality of the knowledge generated through the positive effect on scientific impact.

4.3. Robustness checks

We conducted several robustness checks. First, we replicated the analysis in Tables 4 and 5, employing an alternative indicator by setting a threshold of the 5% most highly cited papers (see Appendix Tables A3.1 and A3.2). The results for the 5% most highly cited papers are similar to the results from our main model in terms of the sign of the association and the significance levels. Second, our independent variable *response mode* combines two different activities (consulting and contract research) associated with academic engagement. We re-ran the analyses including these two interaction modes separately rather than as a unique variable. Appendix Table A4 reports the results. The coefficient of *joint research* retains its stronger association with scientific impact compared to *contract research* or *consulting*. This confirms the robustness of our results. Third, we re-ran the analysis using non-standardised variables; the results hardly changed which confirms our main findings (Appendix Tables A5.1 and A5.2). We then replicated all the models, but restricting the sample to scientists who had interacted at least once with a non-academic actor. The signs and significance of our findings are similar to the main regression model (see Appendix Tables A6.1 and A6.2). Finally, we examined whether engagement with

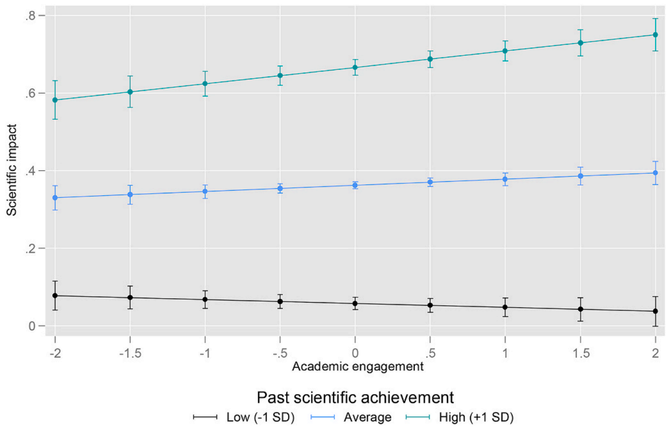

Fig. 2. Predictive margins of the relationship between academic engagement and predicted scientific impact for various levels of past scientific achievement. Note: Low and high values for Past Scientific Achievement are calculated at, respectively, −1 and +1 standard deviations from the mean.

a particular type of actor (i.e., industry) influenced the relationship between academic engagement and scientific impact. We created a dummy variable for scientists who had interacted with an industry partner (SME or large firm). The interaction term between this dummy variable and academic engagement is not statistically significant, suggesting that engaging with industry does not influence the direction or intensity of our main results (see Appendix Table A7).

4.4. Post hoc analysis

We conducted a post-hoc analysis to further investigate the boundary conditions of our main findings, by examining the factors moderating the relationship between academic engagement and scientific impact. First, we tested for a curvilinear relationship. We included a quadratic term of academic engagement (and joint research) and found no statistically significant evidence of either a U- or inverted U-shaped relationship between academic engagement (or joint research) and scientific impact. Second, we examined whether the *strength* of the relationship between academic engagement and scientific impact was influenced by the following three control variables: applied (vs basic) orientation of research; academic rank; and time devoted to research. For the degree of applied orientation of research and the time devoted to research, we built ordered categorical variables with three levels (low, medium, high), each accounting for a tercile of the sample. For academic rank, we used the original categorical variable (i.e., full professor, associated professor, assistant professor, and other).

We found that the relationship between academic engagement and scientific impact was moderated significantly by these categorical variables. Our results show that the strength of the relationship between academic engagement (or joint research) and scientific impact is greater for researchers with a stronger orientation to basic research. We found, also, that the strength of the relationship is greater for scientists in the top academic ranks (i.e., full and associate professor), although this pattern is not statistically significant if we look only at joint research. Finally, our results indicate that the strength of the relationship between academic engagement and scientific impact is particularly strong among scientists who spend a moderate amount of their time on research. In other words, while we did not find decreasing returns for the relationship between academic engagement (or joint research) and scientific impact, this relationship seems subject to boundary conditions. In particular, the strength of the examined relationship is moderated significantly by the scientist's characteristics, such as orientation to basic or applied research, academic rank, and time devoted to research.

5. Discussion

The previous findings examining the relationship between scientists' knowledge-related interactions with non-academic actors (academic engagement) and scientific advances, are mixed. This contrasts with the growing emphasis on the co-production of knowledge and transdisciplinary research in science policy discourse. This study examines whether and to what extent academic engagement results in high scientific impact research.

Our findings suggest that academic engagement is positively associated with scientific impact (Hypothesis 1). Researchers with more frequent interactions with non-academic partners produce more high scientific impact research, measured by the number of top-cited articles. We provide evidence, also, that this positive relationship is contingent on scientific reputation and type of interaction. In the former case, we show that scientists with high levels of peer recognition are better able to exploit the opportunities offered by academic engagement to achieve scientific advancements (Hypothesis 2). We show, also, that joint research (as opposed to response-mode interactions) positively influences the production of cutting-edge research (Hypothesis 3). Therefore, we contend that academic engagement might be conducive to high-impact research results. In relation to the second part of our research question — specifically, the boundary conditions that influence the relationship between academic engagement and scientific impact — we provide several intriguing insights. We show that the relationship between academic engagement and scientific impact is moderated not only by scientific reputation and type of interaction but also by researcher characteristics such as research orientation (basic vs applied science), academic rank, and time spent on research. We found that the positive relationship between academic engagement and scientific impact is stronger for scientists engaged in basic research, more senior academic researchers, and researchers who allocated a moderate amount of time to research. These findings suggest that the positive association between academic engagement and scientific impact is not straightforward, and its strength is influenced by various individual factors.

Our findings contribute to several literature streams and offer various theoretical implications. Previous research on university-industry relations emphasises the challenges that arise when partnerships involve actors from diverse institutional settings. Different norms, cultures and incentive structures can lead to conflicts and coordination problems that may hinder the generation of knowledge (Azoulay et al., 2011; Borah and Ellwood, 2022; Gulbrandsen and Smeby, 2005; Nasirov and Joshi, 2023). However, we found that interactions between academic and non-academic partners can significantly enhance knowledge production and contribute to major advances in science. This positive contribution is dependent on the partners' joint definition of research objectives and priorities, and the opportunities provided for knowledge sharing and knowledge exchange. In the absence of these conditions, we found no evidence of either a positive or negative relationship. For instance, we found that response-mode interactions are neither beneficial for nor detrimental to scientific impact. The positive relationship between academic engagement, in the form of joint research, and scientific impact emphasises the value derived from combining unrelated knowledge and distinct perspectives (Arza, 2010; Beck et al., 2022; Burt, 2004; Gulbrandsen and Smeby, 2005; Kou and Harvey, 2022; Romanova, 2022; Uzzi et al., 2013; Uzzi and Spiro, 2005), despite the coordination challenges of transdisciplinary research. This relationship also emphasises the importance, when analysing academic engagement, of accounting for the level of involvement of the non-academic partner, and the presence of two-way knowledge flows and mutual learning (D'Este et al., 2019; Hakkarainen et al., 2022; Perkmann and Walsh, 2008). Our study also supports the idea that the relationship between academic engagement and scientific impact is moderated by the researcher's past scientific achievements. Scientists with a strong research track record and significant reputation are better able to leverage the opportunities arising from academic engagement and to produce more impactful research. This is in line with Merton's (1988) cumulative advantage theory, which posits that recognised scientists are more likely to benefit from additional resources and opportunities. On the positive side, this finding highlights the potential for high-impact collaborations when experienced and reputable scientists engage with non-academic partners. The ability of more experienced scientists to integrate diverse knowledge bases and develop innovative research is maximised in such collaborations. However, this highlights the issues of equity and access that occur in collaboration networks. If the benefits of academic engagement are disproportionately accessible to scientists with established reputation, then early-career researchers will find it difficult to benefit to the same degree. This could result in a cycle in which only a select group of scientists benefits and increases their reputation while others struggle to break into these high-impact collaborations. For the non-academic partners, these findings highlight the value to be derived from interacting with well-established scientists for achieving high-impact research results. However, this might not be the priority for the non-academic partner. Partnering with a broader spectrum of researchers, including early-career scientists, might favour fresh perspectives and innovative thinking. Thus, supporting collaborative projects that involve a diversity of research talents could result in a richer, more varied innovation landscape. Last, we identified that researchers' individual characteristics (past scientific achievement, research orientation, time dedicated to research) are important factors moderating the relationship between academic engagement and scientific impact – an aspect not central in the existing literature. It suggests directions for future research.

Our results have some implications for science policy and university managers. Since researchers' performance is increasingly assessed by funding agencies based on the scientific impact of their output, the finding that academic interactions with non-academics complement academic research is particularly noteworthy. Our findings suggest that academic engagement is not only beneficial for addressing societal challenges, but also increases the chances of production of cutting-edge research findings: thereby satisfying the twin goals of scientific impact and societal relevance that underpin the research evaluation system. Funding bodies should consider the dual benefits derived from academic engagement and provide grants and resources that encourage such collaborations. At the same time, university administrators should prioritise capacity-building initiatives to promote interaction between researchers and non-academic partners, to foster knowledge sharing and knowledge exchange. Engagement in these types of partnerships is likely to add to the researcher's skills and provide the resources required for the production of high-impact collaborative research. Academic organisations should provide institutional support for networking, opportunities for collaborative workshops and provision of training. Early-career researchers and those with less experience of interaction with non-academic partners would benefit from mentoring programmes. This would help to ensure that researchers at all career levels were able to benefit from collaboration and interactions with non-academic actors. Moreover, while joint research projects with non-academic partners seem to be particularly beneficial for the production of high-impact scientific results, engagement in response-mode interactions might play a crucial role in providing a solid foundation for ambitious and challenging collaborations. Yoshioka-Kobayashi and Takahashi (2022) highlight that in university-industry collaborations, industry actors often prefer initial short-term contracts, open to renewal or extension, depending on the perceived technological learning and social ties. This suggests that response-mode interactions are likely to lead to joint research projects. More research is needed to explore this temporal dynamic and potential academic engagement sequence. We suggest that universities should include strategies designed to enhance academic engagement in their research planning and evaluation frameworks. This could reduce the perceived complexities involved in academic engagement and contribute to both scientific advancements and addressing societal needs.

In the context of the Spanish academic system and ongoing policy debate, our study provides compelling evidence that incentivising scientists' collaboration with non-academic actors, especially in joint research, can be particularly beneficial to the production of high-impact scientific research. Our paper highlights the need to improve levels of academic engagement in Spain to boost the country's scientific excellence. Generalisation of our findings to different national contexts needs to take account of the specific national science, technology and innovation policy frameworks.

Our study has some limitations. Although the indicators we used to capture scientific impact have been employed in the existing literature, our approach has some inherent shortcomings. On their own, citation-based indicators may not fully capture the various ways that a researcher's output might influence the particular scientific field. Future work should consider a more comprehensive set of researcher impact metrics, such as *altmetrics*, case studies or expert peer evaluations. Also, our indicator of scientific impact is based on forward citations over a five-to-seven-year period and may not account for the so-called Sleeping Beauty publications which have gone unnoticed for several years (He et al., 2018; Ke et al., 2015; Van Raan, 2004; Wang et al., 2017). This would suggest that our analysis might not be capturing the delayed impact of some publications and may underestimate the long-term influence of those publications that become prominent outside the period of our analysis. Future work could consider a larger citation window. Also, although we rely on two data sources, our analysis is constrained by its cross-sectional nature, which limits our capacity to identify causality. In addition, although both the research activities analysed and the publications considered refer to the same time period, we cannot assume that the publications identified are the result only of particular research practices. We need to identify a more robust association between academic engagement and the production of highly cited papers. In follow-up research, we plan to conduct interviews with scientists to investigate in more depth whether and to what extent academic engagement influences scientists' research performance.

In the course of our research, several open questions emerged, which suggest areas for further exploration. We have identified multiple directions for research that would increase our understanding of the complex relationship between academic engagement and scientific impact. First, although we found a positive association between academic engagement and scientific impact, we cannot definitively establish the underlying mechanisms. Our study draws on existing literature and theoretical frameworks to hypothesise and subsequently explain this positive association. Future empirical research is needed to investigate and elucidate the specific mechanisms driving this relationship. We need, also, to know more about the influence of academic engagement and its temporal sequence. Future work could investigate whether initial response-mode interactions, such as consulting or short-term collaborations, evolve into more intense joint research partnerships and how this progression affects scientific outcomes. The long-term effects of academic engagement also require further exploration and a focus on how sustained interactions with non-academic actors affect the scientific impact and career trajectories of researchers over time. Capacity building is also important and future research could assess the effectiveness of different training programmes for preparing researchers to interact with non-academic partners. This should include the examination of the impact of facilitating networking opportunities on the initiation and success of academic engagement, providing guidance to the design of programmes oriented to equip researchers to manage and exploit these interactions. Future research also could evaluate the effectiveness of different funding models for supporting academic engagement and the production of high-impact science. Studying the types of strategies that universities could employ to foster productive academic engagement, would be valuable for institutional policy-making. Finally, we need new evaluation metrics. Current measures of scientific impact tend to rely heavily on publication and citation counts, which may not fully capture the broader impacts of academic engagement. Future research could develop and test new approaches that better reflect the multifaceted nature of research impact, including its societal contributions and outcomes. By addressing these research questions, future studies can deepen our understanding of how academic engagement influences scientific and societal outcomes and ultimately guide more effective policies and practices.

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Declaration of competing interest

The authors declare that they have no conflict of interest that could have influenced this work.

CRediT authorship contribution statement

Carolin Nast: Conceptualization, Investigation, Methodology, Software, Validation, Writing – original draft, Writing – review & editing, Project administration. **Oscar Llopis:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – review & editing, Funding acquisition. **Dima Yankova:** Conceptualization, Investigation, Methodology, Software, Validation, Writing – review & editing. **Pablo D'Este:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Writing – review & editing, Funding acquisition.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.technovation.2024.103112.

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