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MINDING THE COMMUNICATIONS GAP: HOW CAN UNIVERSITIES SIGNAL THE AVAILABILITY AND VALUE OF THEIR SCIENTIFIC KNOWLEDGE TO COMMERCIAL ORGANIZATIONS?

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ABSTRACT

We posit that a communications gap exists between universities and commercial organizations, attributed to their idiosyncratic goals, interests, and incentives. To bridge this gap, universities need to recognize and leverage observable differences in *the strength of signals* and *the width of channels* used to disseminate their scientific knowledge externally. We explore these ideas by analyzing knowledge dissemination and academic engagement activities in 133 UK universities in the period 2011–2019. Our analysis shows that universities with a *lower scientific impact* have a higher intensity of collaborative research, contract research, and consultancy activities if they communicate that impact through more prominent scientific outlets. In turn, universities with a *higher scientific impact* have a lower intensity of interaction with commercial organizations if they communicate their scientific impact through less prominent scientific outlets. We further reveal that universities with a *higher economic impact* show a higher intensity of collaborative research. At the same time, we find no evidence that the *social impact* generated by universities is linked to the intensity of university-industry interaction, no matter the channels through which that impact is communicated. Using these findings, we draw implications for practice and policy.

KEYWORDS: university-industry interaction; scientific impact; economic impact; social impact; signaling theory; collaborative research; contract research; academic consulting

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1. INTRODUCTION

As Mokyr (2002, p.9) correctly notes, *economic progress depends not only on creating useful scientific knowledge but also on its effective dissemination* – or, as he astutely phrases it, "knowing that something is known and knowing how to find it." This observation, *inter alia*, highlights the source of a critical obstacle for productive interaction between the academic and business worlds (Bikard and Marx, 2015; Fontana *et al.*, 2006). More specifically, universities are often tasked to utilize the scientific knowledge they generate by engaging with commercial organizations, who can leverage that knowledge to facilitate their explorative and exploitative capabilities and, consequently, propel economic progress (Bishop *et al.*, 2011; D'Este and Patel, 2007; Markman *et al.*, 2008). However, it is usually difficult for commercial organizations to discover university-generated scientific knowledge and assess its commercial potential without preexisting connections, relationships, or a knowledge intelligence system (Fontana *et al.*, 2006; Lawson *et al.*, 2016; Spithoven *et al.* 2011; Tartari *et al.*, 2012).

For instance, according to a commercial organization interviewed in a report by the UK National Centre for Universities and Business (NCUB, 2015, p.49; emphasis added), "*[m]ost of our communication tends to because there's relationships… somebody went there, or somebody's worked with them in the past. It's not because we have* ***a good communication system*** *that tells me x or y research institute is up to this or that. There doesn't seem to be a nice forum for finding information, it tends to be experience and personal contacts.*" Another commercial organization further explains the issue, stating that "*[t]he problem is that you know that there is a university out there that will have the expertise that you need to access but* ***we certainly wouldn't have known which university to approach***" (NCUB, 2015, p.49; emphasis added).

As evident from the preceding quotes, the significance of science communication for universities to convey the availability and value of the scientific knowledge they generate to commercial organizations is widely acknowledged. Multiple reports commissioned by the UK

Government urge British universities to improve their ability to identify and communicate their areas of comparative scientific strength, with the aim of fostering university-industry interaction (Lambert, 2003; Wilson, 2012; Dowling, 2015). One proposal suggests the establishment of a new covenant between universities and commercial organizations that would encourage greater science communication and understanding. In response, the UK Government has introduced the assessment of impact as part of the Research Excellence Framework, a system designed to evaluating the excellence of research in British universities. The aim of this policy measure is to help universities better communicate the purpose and quality of their scientific knowledge (Khazragui and Hudson, 2015; UK Parliament, 2014). However, there is a lack of systematic theoretical understanding and empirical evidence on *how* universities can effectively signal the availability and value of their scientific knowledge to commercial organizations. It is also unclear whether utilizing impact as a measure of research excellence is linked to a discernible increase in university-industry interaction, or if impact is just a consequence of such interaction (Fini *et al.*, 2019; Perkmann *et al.*, 2013; 2015).

In our study, we adopt the university perspective and, following past research that uses signaling theory (Arrow, 1971; Fontana *et al.*, 2006; Ray and Sengupta, 2022; Spence, 1973), develop a conceptual framework that explains how universities can utilize impact as a signal to overcome communication difficulties in university-industry interaction. These difficulties arise primarily from information asymmetries and the communications gap shaped by differences in the organizational and commercial logics, as well as the geographical and cognitive distances between universities and commercial organizations (Antonelli, 2008; Ambos *et al.*, 2008; Borah and Ellwood, 2022; Bruneel *et al.*, 2010; 2016; Fini *et al.*, 2019; Partha and David, 1994; Siegel *et al.*, 2003). One way in which universities can reduce information asymmetries and overcome the communications gap is by managing differences in *the strength of signals* and *the width of channels* that they rely on to disseminate their scientific knowledge externally. By deploying an appropriate combination of signals and channels, universities can enhance the effectiveness of the integrative search strategies utilized by commercial organizations, which draw on a set of screening activities to combine their internal expertise with external knowledge (Criscuolo *et al.*, 2018; Fontana *et al.*, 2006; Laursen and Salter, 2004), and facilitate university-industry interaction in such forms as collaborative research, contract research, and academic consultancy.

We test our propositions and obtain initial empirical evidence using a panel of 133 UK universities observed between 2011 and 2019. To capture *signal strength*, we utilize measures of their scientific, economic, and social impact. In turn, *channel width* is captured by examining a range of communications outlets, either scientific or media, that universities can use to share their scientific discoveries and technical advances with a variety of audiences. In contrast to conventional wisdom, we find that scientific impact benefits the intensity of university-industry interaction if the impact is *stronger* and disseminated through *less prominent* scientific outlets. Dissemination through *more prominen*t scientific outlets is, in turn, found to be beneficial for the intensity of university-industry interaction when the impact is *weaker*. We further find that the economic impact generated by universities has a positive association with the intensity of collaborative research; however, it has no association with the intensity of income from contract research or consultancy activities. Finally, we find no evidence that social impact assists with the intensity of academic engagement, no matter the channel through which it is transmitted.

As such, our study offers several contributions to the existing literature. First, it extends the academic engagement literature (e.g., D'Este and Patel, 2007; Perkmann *et al.*, 2011; 2015; Siegel *et al.*, 2004) by developing an organizational-level conceptual framework that explains how universities can make use of their scientific, economic, and social impact as a signal to foster their interaction with commercial organizations. Second, it also expands the use of the signaling perspective in analyzing academic engagement (e.g., Fontana *et al.*, 2006; Ray and Sengupta, 2022) by identifying the main sources of the communications gap existing between universities and commercial organizations, as well as suggesting what types of signals to focus on and what channels – or intermediaries – to involve in order to effectively transmit those signals. Our study, therefore, responds to calls for more research on the organizational and institutional mechanisms that can facilitate knowledge transfer by reducing uncertainty and search costs (see Fini *et al.*, 2019). Finally, we add to the literature on science communication (e.g., Brossard, 2013; Bubela *et al.*, 2009; Pitsakis *et al.*, 2015; West, 2008) by demonstrating that universities can make their scientific knowledge more accessible to a wider audience, including potential collaborators in industry, by employing an appropriate mix of signals and channels for transmission.

2. THEORETICAL PROPOSITIONS AND CONCEPTUAL FRAMEWORK

2.1. University-industry interaction: The signaling theory dimension

Academic engagement, typically defined as knowledge-related collaboration between universities and commercial organizations, is a topic of enduring interest (Perkmann *et al.*, 2013; 2021).[2] Research in this area concentrates on three key issues: (1) *the antecedents* of academic engagement; (2) *the context* in which universities interact with commercial organizations; and (3) *the consequences* of such engagement for teaching, research, and the economy and society as a whole (Fini *et al.*, 2019; Perkmann *et al.*, 2021). For example, an individual's demographic characteristics, previous experience, and research productivity are all found to have a significant impact on university-industry interaction (D'Este and Patel, 2007; D'Este *et al.*, 2019; Giuliani *et al.*, 2010; Gulbrandsen and Thune, 2017; Link *et al.*, 2007; Tartari and Salter, 2015). At the same time, less attention is paid to the effects of organizational and institutional contexts on the extent and intensity of academic engagement. Indeed, current research primarily focuses on studying organizational quality, the importance of the affiliation with an applied scientific

[2] The existing research on university-industry interaction also examines academic entrepreneurship, which entails developing intellectual property and creating new firms by academic staff (for a detailed review of the topic, see Perkmann *et al*., 2013; 2021). Despite sharing some similarities with our core topic of *academic engagement*, *academic entrepreneurship* is a distinct concept that is not the focus of our study.

discipline, as well as peer effects (Aschhoff and Grimpe, 2014; Bekkers and Bodas Freitas, 2008; Tartari *et al.*, 2014; Thursby and Thursby, 2011; Schuelke-Leech, 2013).

Considering the relatively less attention paid to *non*-individual determinants of academic engagement, and also the challenges that universities tend to face in reaching out to prospective industry partners, the question remains: *what organizational and institutional mechanisms can be utilized to facilitate university-industry interaction*? One approach to answering this critical question is to frame this interaction using signaling theory (Arrow, 1971; Fontana *et al.*, 2006; Ray and Sengupta, 2022; Spence, 1973). Simply put, academic engagement can be viewed as a process with inherent information asymmetries about the availability and value of university-generated knowledge. These asymmetries are further complicated by the communications gap between the interacting parties (i.e., universities and commercial organizations), arising from the idiosyncratic goals, interests, and incentives of each party. To enhance the discoverability of such knowledge and close the communications gap, we posit that one party needs to employ an appropriate mix of signals and channels so that the other party can execute its knowledge search strategy in an effective way. During this interaction process, both parties may also rely on intermediaries. By acting as arbiters of quality, these intermediary entities can help reduce information symmetries and, as such, lower search and transaction costs.

In structuring the rest of our theory development, we will draw on this generic framing to develop a range of testable propositions to demonstrate how applying our framing can help us better understand and improve university-industry interaction.

2.2. The sources of the communications gap between universities and commercial organizations

Generally, academic researchers are incentivized by their universities to disseminate their scientific discoveries and technical advances through a variety of outlets, including books, peer-reviewed journals, working papers, and conference proceedings and presentations. To uphold the integrity of scientific research, each outlet usually has editors and reviewers who rigorously evaluate the ideas, methods, and any accompanying software code or experimental data before making the decision to publish them (de Ridder, 2019). The publication process itself aims to assist academic researchers in transforming their private ideas into public goods that improve the accessibility of knowledge artifacts, thereby supporting further non-profit research activities in academia or for-profit efforts by industry (Antons *et al.*, 2019). After publication, the scientific discoveries and technical advances turn into the collective property of the wider intellectual community, which includes, *inter alia*, academia and industry, and are no longer exclusively owned by its originators or their universities (Miller, 2015; Roth and Lee, 2004).

In turn, commercial organizations often engage in integrative search strategies seeking to combine their internal expertise with complementary sources of external expertise, such as scientific knowledge produced by universities (Köhler *et al.*, 2012; Laursen and Salter, 2004; 2006; Spithoven *et al.*, 2011). Prior studies confirm that industry scientists in various economic sectors use publicly-reported findings from academic researchers in their commercial endeavors (Caloghirou *et al.*, 2021; Cohen *et al.*, 2002; Geuna and Muscio, 2009). This is due to the fact that leveraging a *combination of internal and external expertise* tends to be more effective in improving innovation performance than relying *solely on either internal or external expertise* (Cassiman and Veugelers, 2006; Criscuolo *et al.*, 2018; Grimpe and Kaiser, 2010; Rosenkopf and Nerkar, 2001; Tether and Tajar, 2008). At the same time, commercial organizations may find it challenging to identify relevant and valuable knowledge when sourcing it from universities. This challenge arises from discernible differences in organizational and commercial logics,[3] as well as geographical and cognitive distances between universities and commercial organizations

[3] Some studies refer to differences in organizational and commercial logics as institutional distance or proximity (see Crescenzi *et al*., 2017; Ponds *et al*., 2007). Here, we use the term "logic" to emphasize the way of thinking as a plausible driver of decision-making processes in the pursuit and management of university-industry interaction.

(Antonelli, 2008; Ambos *et al.*, 2008; Borah and Ellwood, 2022; Bruneel *et al.*, 2010; 2016; Fini *et al.*, 2019; Perkmann and West, 2015; Partha and David, 1994; Siegel *et al.*, 2003).

In terms of *organizational logic*, universities place emphasis on upstream theoretical research, while commercial organizations focus on downstream practical research (Gulbrandsen and Smeby, 2005; Thursby and Thursby, 2002; Trajtenberg *et al.*, 1997; Van Looy *et al.*, 2004; 2006; West, 2008), which is reflected in incentives for employees. On the one hand, academic researchers may prioritize career incentives (e.g., tenure, promotion, and recognition) that give them more freedom to experiment and focus on the ideas that are interesting from the scientific viewpoint but take time to be utilized (Azoulay *et al.*, 2011; Jessani *et al.*, 2020; Merton, 1957; Sormani *et al.*, 2022; Ward and Dranove, 1995).[4] On the other hand, industry scientists may prioritize financial incentives (i.e., royalties, bonuses, and stock options) that foster exploitation behavior, betting more on what works, is applicable for practical use, and can yield short-run reward for both the scientists and their organizations (Ederer and Manso, 2011; Manso, 2011). This divergence is driven by two principal factors: stakeholder governance and time horizons. Universities have weaker research oversight and broader governance authority due to diverse stakeholder groups; in contrast, commercial organizations have tighter research oversight and narrower governance authority due to more concentrated stakeholder groups (Jongbloed *et al.*, 2008; McCann *et al.*, 2022; Miller *et al.*, 2014; Radko *et al.*, 2022; Siegel *et al.*, 2003). Moreover, universities typically have longer time horizons precisely because they are less susceptible to immediate demands from their stakeholders and competitive market forces (Bjerregaard, 2010; Borah and Ellwood, 2022; Mannak *et al.*, 2019; Santoro and Chakrabarti, 1999).

Universities and commercial organizations also have different priorities when it comes to *commercial logic*. While universities are non-profit educational institutions mandated to serve

[4] In this sense, academic engagement differs from academic entrepreneurship, where financial incentives may play an important role in motivating the commercialization of scientific knowledge by academic researchers (e.g., Bercovitz and Feldman, 2008; D'Este and Perkmann, 2011; Lach and Schankerman, 2008).

the public interest, commercial organizations are for-profit enterprises aimed at delivering value to their target markets (Argyres and Liebeskind, 1998; Lacetera, 2009; Masten, 2006; Merton, 1973; Scott, 2006). This results in universities allowing academic researchers to focus on internal exploration of ideas that may be academically interesting, but may not always receive sufficient attention for their commercial potential (Link *et al.*, 2007; Siegel *et al.*, 2003; 2004). Conversely, industry scientists may focus on searching for external ideas that have clear commercial appeal, often without fully considering their academic relevance (Laursen and Salter, 2004; 2006). In addition, universities often prioritize the disclosure and dissemination of scientific knowledge as a public good; in turn, commercial organizations may prioritize knowledge protection to avoid the free rider problem (Merton, 1973; Nelson, 1959; 2001; Pisano, 2006; Teece, 1986). Despite the increasing number of patents filed by universities, the profitable licensing of these patents remains elusive for most universities (Bulut and Moschini, 2009; Geuna and Nesta, 2006). As such, universities are less market-aware and may operate at a disadvantage in understanding and communicating the commercial potential of their scientific knowledge (Colyvas *et al.*, 2002; Czarniawska and Genell, 2002; Elfenbein, 2007; Geuna and Muscio, 2009; Nelson, 2004).

Finally, the *distance* separating universities from commercial organizations also plays a key role in creating the communications gap. There are two forms of distance that are especially relevant in this case: geographical and cognitive.[5] For example, a shorter geographical distance between universities and commercial organizations fosters bidirectional knowledge spillovers via increased joint research activities and face-to-face contacts, with the latter being crucial if there is uncertainty about the availability and value of scientific knowledge (Abramovsky and Simpson, 2011; Audretsch and Feldman, 2004; Belenzon and Schankerman, 2013; Bikard and Marx, 2020; Bishop *et al.*, 2011; D'Este *et al.*, 2013; Laursen *et al.*, 2011; Ponds *et al.*, 2007).

[5] We should note that university-industry interaction at the individual level is also affected by social distance, which is "the socio-economic environment in which individuals are embedded" (Crescenzi *et al.*, 2017, p.735). Since our study examines this interaction at the organization level, we do not explicitly consider this type of distance.

Cognitive distance refers to the difference in how universities and commercial organizations perceive, interpret, and understand the world (Villani *et al.*, 2017). A shorter cognitive distance facilitates academic engagement because it reduces communication and coordination costs that stem from the difficulties experienced by individuals from different knowledge domains when they need to productively interact with each other (Crescenzi *et al.*, 2016; Kotha *et al.*, 2013; Muscio and Pozzali, 2013; Nooteboom *et al.*, 2007). Thus, greater geographical and cognitive distances may further increase the communications gap between universities and commercial organizations, with a corresponding negative effect on university-industry interaction.

2.3. The use of signaling to close the communications gap in university-industry interaction

As we explain above and summarize in Table 1 below, the apparent communications gap poses a key challenge for knowledge sharing and productive interaction between universities and commercial organizations. Based on this general observation, we contend that a potential solution for closing the communications gap is to carefully understand how universities can signal the availability and value of their scientific knowledge. This signaling allows prospective industry partners to effectively screen this essential information. Relatedly, we contend that the signaling process primarily relies on the engagement with such intermediary institutions as scientific communities, patent offices, and media outlets. These institutions must be credible, independent, and mutually recognized to act as arbiters of the quality of scientific knowledge, thus lowering the search and transaction costs of university-industry interaction.

=== Table 1 is about here ===

To better understand the signaling process, we propose the following conceptualization. Our key idea is that universities can signal the availability and value of their scientific knowledge through three types of signals transmitted through distinct channels (see Figure 1):

(1) signals to members of scientific communities transmitted through scientific outlets;

(2) signals to economic agents transmitted through patents[6] and patent offices; and

(3) signals to members of society at large transmitted through media outlets.

The *strength* of each signal is determined by the amount of attention it is able to attract, thereby generating scientific, economic, and social impact, respectively (Tennant *et al.*, 2016). Each channel has its *width* that affects the signal's strength and is determined by the characteristics of the associated intermediary transmitting the signal. Below we discuss each signal type and the role that each corresponding intermediary plays in the signaling process, with the objective of deriving useful implications for academic engagement.

2.3.1. Signals in the form of scientific impact and the role of scientific communities

New ideas that academic researchers come up with are usually disseminated (or signaled) by publishing them in scientific articles, conference proceedings, and books. The publication process enables these ideas to be turned into scientific knowledge, with scientific communities acting as a critical intermediary in this process. We define scientific communities as including a variety of disciplinary associations, professional societies, and other similar organizations that "identify specific areas of inquiry as their own and provide opportunities for like-minded groups of individuals to coordinate research agendas" (Huff, 2000, p.288). These groups act as a thought collective, which essentially means they are a "community of scientists working on the basis of joint convictions as to which knowledge shall be considered proved, which methodologies are scientifically valid, and which criteria of scientificity are acceptable" (Fleck, 1979; Schnelle, 1981, p.733). Thus, scientific communities guide new knowledge generation, advance scientific discourse, and drive scientific impact primarily by publishing scholarly journals and convening conferences and forums for discussion and debate (Antons *et al.*, 2019).

[6] Here, we use the term "patents" to refer to a channel of scientific knowledge dissemination, rather than an asset possessed by a university. For example, similar to journal articles, patents also contain references to academic research. This means that patents can be used as another channel for disseminating scientific knowledge. Yet, we are not currently analyzing how universities use patents in order to signal the appropriation of their scientific knowledge, which is an interesting topic for future research.

It is important to acknowledge the sheer volume and size of the world's collective body of scientific knowledge (Antons *et al.*, 2023). Since the publication of the first academic journal in 1665, over 50 million peer-reviewed scholarly articles have been published, and the number continues to grow, with more than 2.5 million articles added to a collection of over 20,000 peer-reviewed academic journals each year (Jinha, 2010; Ware and Mabe, 2015). As discussed earlier, the organizational and commercial logics of universities incentivize academic researchers to disseminate their new ideas through the extensive network of scientific communities, ultimately turning these ideas into public goods. This incentive system influences behavior, as academic researchers are motivated to publish their work in order to disseminate their findings, advance their careers, and secure funding (Ware and Mabe, 2015). Commercial organizations, in turn, recognize the crucial role played by scientific communities as arbiters of the quality of university-generated scientific knowledge. As a result, they rely on signals from scientific communities when executing their integrative search strategies (Fontana *et al.*, 2006).

However, the vast amount of scientific knowledge produced by and residing in scientific communities tends to make it difficult to effectively search for relevant information. We contend that the intensity of university-industry interaction may increase if universities also adopt a more active stance on signaling the availability and value of their scientific knowledge. This means that they need to send stronger signals through suitable intermediaries to help their prospective industry partners with the screening process. One way to capture the signal's strength is to rely on citation counts from academic sources. Citation counts are among the most commonly used metrics for measuring the consumption of scholarly output, as they show the scientific impact of the underlying knowledge (Shafique, 2013; Tahai and Meyer, 1999). Internally, citation counts are a critical measure, albeit not without limitations, for universities to evaluate how well their researchers are doing in producing scientific knowledge (Abramo and D'Angelo, 2011; Wang, 2013; Wilhite and Fong, 2012). Externally, they can be a meaningful indicator for commercial organizations to determine who else is consuming university-generated scientific knowledge (Ceballos *et al.*, 2017). Thus, when commercial organizations search the landscape of published academic research for ideas that have market potential, their screening process may take notice of highly-cited pieces of scientific knowledge and utilize this information to initially identify potential partners or collaborators.

The strength of scientific impact as a signal can subsequently be affected by the width of the channel – or the prominence[7] of the scientific outlet through which it is transmitted. For example, journal rank or status, which are alternative terms for prominence, can help maximize the efficiency of locating high-impact research (Stringer *et al.*, 2008). In addition, the prominence of scientific outlets can also reflect the size of the audience they are able to reach, meaning that scientific discoveries and technical advances published in prominent outlets are more likely to be noticed by a wider audience (Van Fleet *et al.*, 2000; Zitt and Small, 2008). By drawing on journal prominence as an important element of their signaling strategy, universities can increase the discoverability of their scientific knowledge by prospective industry partners, thus reducing information asymmetries in university-industry interaction (Drivas and Kremmydas, 2020).

Based on the above arguments, we present our first set of propositions:

Proposition 1(a): The greater the *scientific impact* (stronger signal) of the knowledge generated by universities, the more intense the university-industry interaction.

Proposition 1(b): The link between universities' *scientific impact* and the intensity of their interaction with industry partners is positively moderated by the *prominence of the scientific outlets* (wider channels) through which they communicate this impact.

2.3.2. Signals in the form of economic impact and the role of patent offices

As a public good, scientific knowledge can move outside scientific communities and be used to inform inventive activities, thereby yielding economic impact. In this case, patents can be viewed as a vehicle that carries the signal about the private utility value of this public good

[7] We follow Rindova *et al*. (2005, p.1035) in defining prominence as "the extent to which an organization is widely recognized among stakeholders in its organizational field."

knowledge, with patent offices acting as a principal intermediary in supporting the integrity of the signaling process. Patent offices are governmental organizations that assign formal patent rights to inventors with the aim of conferring exclusive intellectual property protection. When filing a patent application and constructing claims, the inventor must cite the relevant prior art upon which their invention is based. This is an integral element of the patent application process, given that the scientific knowledge that is already in the public domain is, by definition, non-patentable. Although the prior art mostly consists of patents issued earlier, it also includes any published academic research (Bikard and Marx, 2020; Marx and Fuegi, 2020; Popp, 2017).

Reportedly, only about 10% of scientific discoveries at universities are patented, leaving the rest in the public goods domain (Belenzon and Schankerman, 2013).[8] In turn, commercial organizations filing patent applications are increasingly citing academic research. According to Marx and Fuegi (2020), approximately 17.6% of the US patents granted since 1947 contain at least one citation to scientific research on their front page. This trend is growing, rising from 6.7% in 1976 to 25.6% in 2018. On average, US patents have 1.99 citations to scientific research, a substantial increase compared to the period before 1980, when patents had less than one citation on average. However, in recent years, the average number of citations per patent exceeds four. Recognizing this trend, we assume that patents, along with the appropriability function, are also turning into valuable sources of information for commercial organizations about the commercial potential of university-generated scientific knowledge.

In order to measure the strength of this signal, citations made by patents to the scientific knowledge produced by universities can be utilized. These citations capture the extent to which

[8] We note that not all scientific discoveries from universities are patentable or universities may choose not to patent them (Andersen and Rossi, 2011). In general, the conditions for patentability include novelty, non-obviousness, industrial application, and the requirement of patentable subject matter (e.g., a mathematical theorem cannot be patented) and the need to disclose the invention (some inventors may be reluctant to do so). In addition, the patenting behavior of academics varies significantly not only in terms of their scientific discipline but also due to the incentive structure at universities. Academic researchers are found to have incentives to patent in their late career when their motivation to publish is known to decrease sharply (Carayol, 2007).

commercial organizations use such knowledge when conducting their own research (Meyer, 2000; Pavitt, 1998). Since patent examiners independently assess the quality of an invention in terms of its novelty, usefulness, and non-obviousness, in-patent citations to scientific knowledge from universities may also be a feasible and reliable way for commercial organizations to screen for high-quality knowledge (Arora *et al.*, 2021; Bikard and Marx, 2020; Poege *et al.*, 2019). These citations may further show that university-generated knowledge is relevant for industrial inventive activities and, hence, more likely to have commercial value if it is cited frequently. Although this tends to be a passive signaling strategy in the sense that academic researchers cannot actively select themselves into being featured in or referenced by patents (this is typically done by the applicant or the patent examiner), in-patent citations to the knowledge generated by universities may improve its discoverability by prospective industry partners and facilitate university-industry interaction by lowering search costs.

Based on the preceding arguments, our next proposition is that:

Proposition 2: The greater the *economic impact* (stronger signal) of the knowledge generated by universities, the more intense the university-industry interaction.

2.3.3. Signals in the form of social impact and the role of media outlets

Beyond scientific and economic impacts, university-generated scientific knowledge can also be communicated through media outlets, which increases its social impact (Pitsakis *et al.*, 2015). Media outlets are defined as print and online publishers of news content distributed to non-academic audiences regionally, nationally, or internationally. In comparison to the limited technical readership of most scientific journals and the smaller user groups of patent databases, media outlets serve a much broader audience comprising both individuals and organizations. News items and stories that are featured in media outlets can raise general public awareness and engagement regarding the potential benefits of scientific discoveries and technical advances, enabling them to develop informed opinions on the matter (Rindova *et al.*, 2007). By capturing the public's attention and imagination, this not only gives support for maintaining and increasing research funding in emerging areas but also stimulates latent demand for resulting inventions, thus attracting interest from commercial organizations (Brossard, 2013; Bubela and Caulfield, 2004; Bubela *et al.*, 2009). Importantly, the public often perceives media outlets as authoritative sources of information, enabling them to play an intermediary role in communicating scientific knowledge (Pollock and Rindova, 2003; Rindova *et al.*, 2007).

Individual academic researchers tend to recognize the benefits of engaging with media outlets in order to facilitate the broader dissemination of their scientific knowledge, and they are typically supported by their universities in doing so (Chikoore *et al.*, 2016).[9] Within universities, the task of working with mass media falls under the purview of the faculties' communications and public relations activities, as they act as intermediaries between the universities and media outlets (Sá *et al.*, 2011). In turn, commercial organizations may rely on mentions in media outlets to stay informed about the latest scientific discoveries and breakthroughs (Frølund *et al.*, 2018). Therefore, media mentions may serve a similar purpose as citations from scientific outlets or patents, with a greater number of mentions indicating a higher social impact and relevance of the underlying knowledge. From a screening perspective, mentions in media outlets may reduce search costs and enhance the discoverability of university-generated scientific knowledge for commercial organizations. After becoming aware of the existence of this knowledge through media mentions, commercial organizations may explore the original publications that reported it or the subsequent patents that utilized it as part of their evaluation of its commercial potential and applications (Anderson *et al.*, 2020; Arora *et al.*, 2018; Tijssen, 2002; Zahra *et al.*, 2018).

Additionally, the strength of the signal transmitted through media outlets is likely to be determined by the prominence of those outlets, which may be ascertained, for example, from the size of the audience they can reach (e.g., local, national, or international). To assist the screening

[9] Chikoore *et al.* (2016) also found that, while understanding the importance of engaging with different audiences, academic researchers oppose the idea of making public engagement mandatory as part of the appraisal system.

process undertaken by commercial organizations, universities may adopt a proactive approach in selecting the media channels through which they communicate their scientific knowledge. They may opt for more prominent outlets that can not only enhance the discoverability of the knowledge due to a wider reach but also, through their reputation and authority, give a credible endorsement perceived as the assurance of knowledge quality (Bubela and Caulfield, 2004; Deephouse, 2000). Hence, signaling through media outlets should not be seen as a completely passive strategy, where media outlets solely decide which scientific discoveries and technical advances to highlight. Instead, universities can actively deploy this strategy by working closely with prominent media outlets to effectively communicate the scientific knowledge they produce to non-academic audiences. By doing so, universities can bridge the communication gap and, ultimately, promote university-industry interaction.

Based on the above arguments, we present our final set of propositions:

Proposition 3(a): The greater the *social impact* (stronger signal) of the knowledge generated by universities, the more intense the university-industry interaction.

Proposition 3(b): The link between universities' social impact and the intensity of their interaction with industry partners is positively moderated by the *prominence of the media outlets* (wider channels) through which they communicate this impact.

In summary, our propositions suggest that stronger signals transmitted through broader channels are associated with a higher level of interaction between universities and commercial organizations. This may be attributed to the improved ability of commercial organizations to effectively screen the signals conveyed by universities through such intermediaries as scientific communities, patent offices, and media outlets. These intermediaries act as arbiters of the quality of the underlying scientific knowledge and facilitate its broader dissemination. We will now provide a description of the empirical setting, methods, and data used in our study to quantify and test these propositions (the conceptual framework for our study is presented in Figure 2).

3. DATA AND METHODS

3.1. Empirical context

Our empirical analysis is based on data from the UK higher education sector. In the UK, universities play a crucial role through their two main streams of activities: research and teaching. The academic workforce in the country comprises about 150,000 researchers who collectively publish nearly a quarter of a million units of scholarly output per year. Moreover, UK universities educate an average of 2.5 million students annually.[10] Along with these traditional streams and in response to government policies, universities in the UK are also actively involved in a third and increasingly significant stream – the commercial use of university-driven research (Lockett *et al.*, 2015). This third stream encompasses "all other university endeavours in addition to research and teaching, and is largely focused on the transfer of knowledge from the university to outside individuals and organisations" (Lockett *et al.*, 2013, p.237). Across all streams, UK universities support over 800,000 jobs, generate approximately £95 billion in gross output, and contribute £52 billion to the country's GDP (Frontier Economics, 2021).

3.2. Data collection and the sample

To construct our empirical sample, we mainly rely on information from the UK Higher Education Statistics Agency (HESA), which collects, processes, and publishes statistical data about the higher education sector in the country, including various aspects of university-industry interaction. More specifically, we start with data from the HESA Higher Education Business and Community Interaction (HE-BCI) survey, which we then link to student and staff records also provided by the HESA. Since not all higher education providers (HEPs) produce publishable

[10] The data on academic staff responsibilities is obtained from the HESA staff dataset for the academic year 2020–2021, covering both full-time and part-time research-only staff as well as teaching/research staff. The data on the amount of scholarly output is sourced from the SciVal database for the year 2021, including all types of publications indexed by Scopus. Finally, the data on the average number of student enrolments is obtained from the HESA student dataset for the years 2015–2021, covering both undergraduate and postgraduate students.

research output (e.g., colleges of arts, music, drama, or dance), we exclude them from our sample. We also exclude HEPs with substantial missing data. For the remaining HEPs, we supplement the dataset with such information as the year of establishment, former polytechnic status, and the results of the Research Assessment Exercise (RAE) 2008. Furthermore, we utilize the SciVal database to gather statistics on the publication activities and impact of the sampled institutions. Overall, our sample comprises 133 UK HEPs observed during the period 2011–2019.

3.3. Dependent variables[11]

We focus on three key forms of university-industry interaction (D'Este and Patel, 2007; Perkmann *et al.*, 2011; Rossi, 2018). First, we examine the intensity of collaborative research (*ACADCOLRES*), which is measured by the share of publications (e.g., articles, reviews, books, book chapters, and conference proceedings) produced by academics affiliated with the HEP in collaboration with individuals with a corporate affiliation. The distinction between academic and corporate affiliations is based on the organization type assigned by Scopus.[12] Second, we consider the intensity of income generated by contract research (*ACADCONTRES*). This is calculated as the ratio of the total monetary value of contract research conducted by the HEP with commercial firms to the total number of academic staff. Third, we examine the intensity of income generated by consultancy activities (*ACADCONSULT*), which is measured as the ratio of the total monetary value of consultancy contracts between the HEP and commercial firms to the total number of academic staff. In our study, commercial firms include small and medium enterprises, as well as large private sector businesses. We do not account for the monetary value of contracts with non-commercial and public sector organizations.

[11] For a detailed description of the study variables and their sources, see Table A.1 in the Online Appendix.

[12] The SciVal database uses raw bibliometric data from Scopus, an abstract and citation database of peer-reviewed literature published by Elsevier.

3.4. Explanatory variables

We utilize the field-weighted citation impact index from SciVal to assess the scientific impact of the HEP (*IMPSCI*). The index is calculated as follows:[13]

$$FWCI = \frac{1}{N}\sum_{i=1}^{N}\frac{c_i}{\epsilon_i}, \quad (1)$$

where N represents the number of publications associated with the HEP; c_i denotes the number of citations received by publication i; and ϵ_i signifies the expected number of citations received by all publications similar to publication i in the publication year and the following three years. According to SciVal, similar publications are defined as those indexed in the Scopus database with the same year, type, and discipline. Therefore, a FWCI value of 1 indicates that the HEP's publications receive citations in line with the global average for similar publications. In turn, a FWCI value below/above 1 suggests that the HEP's publications receive fewer/more citations than expected. Drawing on citations received from other articles, reviews, books, book chapters, and conference proceedings, this metric effectively accounts for the degree to which the HEP's research influences scientific communities.

The economic impact of the HEP (*IMPECON*) is assessed using the average number of patent-citations received per 1,000 scholarly outputs published by the university. For example, if a HEP produces 500 scholarly outputs within a one-year period and those outputs receive 20 citations from patents, the patent-citations per scholarly output would be (20/500) × 1,000 = 40. Hence, this measure provides insights into the degree to which the HEP's research contributes to the development of new products and technologies. It includes citations received from patents filed in different patent offices, including the European Patent Office, the Intellectual Property Office of the UK, the US Patent and Trademark Office, the Japan Patent Office, as well as the World Intellectual Property Organization.

[13] The description of SciVal metrics and other related information is available at: https://service.elsevier.com/app/answers/detail/a_id/13936/supporthub/scival/.

We utilize the field-weighted mass media index from SciVal to assess the social impact of the HEP (*IMPSOC*). The index is calculated as follows:

$$FWMM = \frac{1}{N}\sum_{i=1}^{N}\frac{m_i}{\varepsilon_i}, \quad (2)$$

where N represents the number of publications associated with the HEP; m_i denotes the number of mass media mentions received by publication i; and ε_i signifies the expected number of mass media mentions received by all publications similar to publication i in the publication year and the following three years. Therefore, a FWMM value of 1 indicates that the HEP's publications receive mass media mentions in line with the global average for similar publications. In turn, a FWMM value below/above 1 suggests that the HEP's publications receive fewer/more mass media mentions than expected. Drawing on mentions in print media and taking into account the publication type, demographics, and audience reach, this metric captures the degree to which the HEP engages with the broader public, beyond scientific communities and patent offices. It should be noted that media mentions in internationally recognized sources are weighted at 1.0, regionally recognized sources at 0.5, nationally recognized sources at 0.3, locally recognized sources at 0.2, and sources of local interest at 0.1. The assignment of tiers is done by LexisNexis, the source of raw data for this measure, while the weighting is assigned by SciVal.

Lastly, we measure the prominence of the channels through which HEPs communicate their scientific and social impacts. Specifically, we assess the prominence of scientific outlets (*PROMJOURN*) where the HEP's research is published. This is calculated as the proportion of the HEP's research output disseminated through the top 10% of the world's most-cited journals, as determined by CiteScore. These journals are ranked based on the average number of citations received by all items published in each journal in the preceding three years. We also measure the prominence of media outlets (*PROMMEDIA*) that highlight the HEP's research. To do this, we calculate the ratio of mentions in internationally, regionally, and nationally recognized mass media to the total number of mentions in mass media received by publications associated with the HEP. The same weighting as above is applied when counting mass media mentions.[14]

3.5. Control variables

We also include controls for several additional factors that are expected to influence the intensity of university-industry interaction (for more detailed information on how each control variable is calculated, see Table A.1 in the Online Appendix).

The first set of controls is at the organizational level. For instance, we include a control for HEP size (*HEPSIZE*) to capture the scale and resourcefulness of each university as well as account for the possibility that larger universities engage more with commercial organizations (Van Looy *et al.*, 2011). Additionally, we control for whether the HEP is a former polytechnic institution or not (*HEPPOLY*). According to D'Este and Patel (2007, p.1298), polytechnics had "a founding mission to support regional development", which may result in unique patterns of university-industry interaction. Finally, we include a control for the share of patentable subject areas (*HEPPATAR*) in the HEP's portfolio,[15] which accounts for differences in the propensity of various areas to generate commercially valuable knowledge (Crespi *et al.*, 2011).

The second set of controls is related to strategy and incentives (D'Este and Perkmann, 2011; Lockett *et al.*, 2003). Specifically, we include a control for whether the HEP has a fully developed strategic plan for engagement with commercial organizations (*HEPCOMSTRAT*) that can guide university-industry interaction. We also control for the level of incentives provided to academic staff (*HEPINCENT*) to encourage their engagement with commercial organizations. Finally, we include a control for the HEP's cumulative experience with business engagement (*HEPTTOEXP*) using the age of its technology transfer office – a key unit within universities responsible for facilitating their interaction with the industry (Siegel and Wright, 2013).

[14] The results of our empirical analysis are robust even when using the media outlets' prominence measure without the weighting. These results are available from the authors upon request.

[15] For the list of subject areas by their patentability, see Table A.2 in the Online Appendix.

The final set of controls focuses on knowledge creation and dissemination. For example, we include a control for the share of academics with research responsibilities (*HEPRESAC*). As D'Este and Patel (2007, p.1298) note, "[t]he scale of resources, in terms of either academic research personnel or research income, can be considered a necessary condition for attracting industry interest." Additionally, we control for the HEP's research quality (*HEPRESQUAL*), largely due to its ability to generate interest among commercial organizations in the university's scientific research and, therefore, result in a higher intensity of university-industry interaction (Perkmann *et al.*, 2011). To measure it, we rely on the results of the RAE 2008.[16] Finally, we include a control for knowledge dissemination (*HEPPUBL*) in the form of publications (e.g., articles, reviews, books, book chapters, and conference proceedings) associated with the HEP.

3.6. Econometric strategy

To conduct our empirical analysis, we rely on a longitudinal panel of UK universities observed over a nine-year period. We employ the ordinary least squares (OLS) method to obtain parameter estimates. When choosing between random- and fixed-effects model specifications, we follow the results of the Hausman specification test (Hausman, 1978). According to this test, a fixed-effect specification is preferred for modeling individual-level effects. Hence, we adopt it in our empirical analysis. However, instead of using STATA's "*xtreg, fe*" command, we use "*xtreg, re*" and, following the approach of Blundell *et al.* (1999), add the pre-sample mean of each dependent variable to the model specification in order to capture *unobserved* fixed effects. More specifically, for the intensity of collaborative research, we utilize the HEP's five-year pre-sample average (2006–2010) of the proportion of publications that the academics affiliated with the HEP produced with individuals who have corporate affiliations. For the intensity of income from contract research and consultancy activities, we utilize the HEP's five-year pre-sample

[16] The decision to use the results of the RAE 2008 instead of the Research Excellence Framework (REF) 2014 is primarily based on the fact that it allows us to create a pre-sample variable that reflects the HEP's research-related fixed effects (Bettis *et al*., 2014).

average (2006–2010) of the ratio of the total income from research grants and contracts to the total number of academic staff. We use this measure because historical data for these dependent variables were unavailable. Nonetheless, this substitute measure is deemed appropriate as it is a linear function of the same unobserved heterogeneity that affects both dependent variables. According to Lach and Schankerman (2008), this is a necessary condition to proceed with using such a substitute. Blundell *et al.*'s (1999) approach to introducing fixed effects offers a number of advantages. For example, it allows us to relax the assumption of strict exogeneity and obtain consistent estimates under the weaker assumption of a predetermined explanatory variable. In addition, it enables us to estimate the effects of time-invariant controls, including the former polytechnic status and research quality.

It is also worth noting that we apply a log transformation to all our dependent variables to ensure normality. To address simultaneity bias, we lag all explanatory and control variables by one year. Finally, we cluster standard errors at the HEP level in order to allow for arbitrary heteroskedasticity and intra-group correlation.

4. EMPIRICAL RESULTS

4.1. Baseline analysis

Descriptive statistics and the correlation matrix for our study variables are presented in Tables 2 and 3. On average, about 4% of all research conducted by academic staff in the HEPs included in our sample is done in collaboration with individuals who have a corporate affiliation. Regarding the average income from university-industry interaction, contract research generates £1,940 per academic staff member, which is about £420 more than the average per capita income from consultancy activities. Moving on to the impact variables, the average scientific impact of the sampled HEPs (i.e., citations from scientific outlets) is 54% higher than the expected world average. In turn, their average social impact (i.e., mentions in print media) is 31% higher than the expected world average. As for economic impact, there are about 20 patent citations received by 1,000 scholarly outputs published by the HEPs in our sample, suggesting their sizeable impact.

=== Tables 2 and 3 are about here ===

The results of the empirical analysis for the intensity of collaborative research are shown in Table 4. In our analysis, we start with the simplest model that includes only control variables (*Model 1*) and progressively build upon it by incorporating explanatory variables (*Models 2–5*) and then interaction effects (*Models 6–8*). More specifically, we find that the scientific impact generated by HEPs shows a positive direct association with the intensity of their collaborative research. However, the association is only marginally significant (*Model 2*: $\beta = 0.245$; $p < 0.072$), but it remains significant when other impact types, such as economic and social, are included in the model specification (*Model 5*: $\beta = 0.233$; $p < 0.089$). In turn, the economic impact is found to have a positive association with the intensity of collaborative research (*Model 3*: $\beta = 0.0032$; $p < 0.019$; *Model 5*: $\beta = 0.0029$; $p < 0.038$). Finally, we do not find any statistically significant direct association between HEPs' social impact and the intensity of their collaborative research (*Model 4*: $\beta = -0.078$; $p < 0.177$; *Model 5*: $\beta = -0.076$; $p < 0.190$).

To ease the interpretation of the moderating effects, we present them in a graphical form (see Figure 3).[17] Unlike the statistically significant moderating effect of the prominence of the scientific outlets through which HEPs disseminate their scientific knowledge on the association between their scientific impact and the intensity of their collaborative research, we do not find any similar effect of the prominence of media outlets on the association between social impact and the intensity of collaborative research. Regarding the moderating effect of the prominence of scientific outlets, it is more nuanced. Specifically, HEPs with a *weaker scientific impact* (about 1.5 or less of the expected world average for the subject field, publication type, and publication

[17] Following Cumming and Finch (2005) and Schenker and Gentleman (2001), we do not add confidence intervals when plotting marginal effects. Instead, we provide detailed information regarding point estimates, as well as their significance levels and confidence intervals in tabular form in Tables A.3.a–A.3.c in the Online Appendix.

year) are associated with a greater intensity of collaborative research when they transmit a larger portion of their scientific impact through *more prominent scientific outlets*. In turn, HEPs with a *stronger scientific impact* (approximately 1.5 and above of the expected world average) are associated with a greater intensity of collaborative research when they transmit a larger portion of their scientific impact through *less prominent scientific outlets*.

=== Table 4 and Figure 3 are about here ===

Table 5 presents the results of the econometric analysis for the intensity of income from contract research. In contrast to what we observe for collaborative research, there is no evidence indicating a direct association between HEPs' scientific, economic, or social impact and contract research. More specifically, we find that the association between the scientific impact generated by HEPs and the intensity of their income from contract research is not statistically significant (*Model 10*: $\beta = 0.183$; $p < 0.418$; *Model 13*: $\beta = 0.179$; $p < 0.421$). Similarly, there is no statistical evidence that would support an association between HEPs' economic impact and the intensity of their income from contract research (*Model 11:* $\beta = 0.0007$; $p < 0.659$; *Model 13*: $\beta = 0.0006$; $p < 0.704$). Finally, our analysis suggests that the social impact generated by HEPs also shows no association with the intensity of their income from contract research (*Model 12;* $\beta = 0.046$; $p < 0.616$; *Model 13*: $\beta = 0.047$; $p < 0.601$).

However, we find that the moderating effect of the prominence of the scientific outlets through which HEPs disseminate their scientific impact is equally important for both contract research and collaborative research (see Figure 4; the prominence of media outlets, once again, is found to be not statistically significant). Specifically, HEPs with a *weaker scientific impact* (about 1.5 or less of the expected world average) are associated with a greater intensity of income from contract research when they transmit a larger portion of their scientific impact through *more prominent scientific outlets*. In turn, HEPs with a *stronger scientific impact* (approximately 1.5 and above of the expected world average) are associated with a greater intensity of income from contract research when they transmit a larger portion of their scientific impact through *less prominent scientific outlets*.

=== Table 5 and Figure 4 are about here ===

The results of the empirical analysis for the intensity of income from consultancy activities are shown in Table 6. They mirror the results observed for contract research. More specifically, we do not find any statistically significant direct association between HEPs' scientific impact and the intensity of their income from consultancy activities (*Model 18*: $\beta = -0.001$; $p < 0.992$; *Model 21*: $\beta = 0.010$; $p < 0.942$). There is also no direct association between the economic impact HEPs have and the intensity of their income from consultancy activities (*Model 19*: $\beta = -0.0018$; $p < 0.329$; *Model 21*: $\beta = -0.0019$; $p < 0.322$). Finally, we find no direct association between social impact and the intensity of income from consultancy activities (*Model 20*: $\beta = -0.057$; $p < 0.491$; *Model 21*: $\beta = -0.061$; $p < 0.463$).

Unlike the prominence of media outlets, the prominence of the scientific outlets on which HEPs rely to signal their scientific impact does have a differential effect (see Figure 5). As with other modes of academic engagement, HEPs with a *weaker scientific impact* (1.0 or less of the expected world average) are associated with a greater intensity of income from consultancy activities when they transmit a larger portion of their scientific impact through *more prominent scientific outlets*. In turn, HEPs with a *stronger scientific impact* (1.0 and above of the expected world average) are associated with a greater intensity of income from consultancy activities when they transmit a larger portion of their scientific impact through *less prominent scientific outlets*.

=== Table 6 and Figure 5 are about here ===

Overall, our empirical analysis reveals mixed support for our theoretical propositions. In particular, Propositions 1(a) and 2, which pertain to the strength of scientific and economic impacts, respectively, are only supported when considering collaborative research; yet, there is no support for Proposition 3(a) concerning social impact, regardless of the mode of university-industry interaction. Regarding the moderating effects of the prominence of scientific and media outlets, we find support only for Proposition 1(b) but not for Proposition 3(b). However, there is a boundary condition: the prominence of scientific outlets is beneficial for signaling scientific impact and, hence, facilitating university-industry interaction only when the impact itself is at a lower level. Alternatively, signaling the scientific impact through less prominent scientific outlets appears to be a better option when the impact is higher.

4.2. Robustness checks

To ensure the robustness of our results, we conduct a series of checks which are fully reported in the Online Appendix. Here, we provide only a brief discussion. We begin by adopting alternative estimation methods to analyze the data (Wooldridge, 2010). In addition to the OLS model, we also experiment with the Poisson model and the tobit model, considering that all of our dependent variables are non-negative, or limited from below. The results of this analysis (see Table A.4) are generally consistent with the baseline analysis, except for economic impact. We find that it becomes statistically insignificant for collaborative research, but its association with contract research and consultancy activities becomes negative and statistically significant.

Next, we examine whether alternative specifications of the explanatory variables alter our results. The baseline measure of the HEP's scientific impact includes citations from various outlets for disseminating scientific knowledge (e.g., articles, reviews, books, book chapters, and conference proceedings). A more restrictive approach is to consider only scientific articles and reviews. In addition, instead of counting citations, another approach is to count the number of views received by each scientific artifact. In our robustness checks, we experiment with both approaches. Furthermore, we also experiment with the inclusion of mentions in online media as part of the HEP's social impact measure. The baseline version of the social impact measure focuses on print media due to the availability of data on mentions in online media in the SciVal database from 2014 onwards. Consequently, including online media sources would limit the period of our analysis.

Based on the results of these robustness checks, restricting the scientific impact measure to only scientific articles and reviews does not improve our baseline findings (see Table A.5). At the same time, using publication views instead of citations makes scientific impact statistically insignificant across all modes of university-industry interaction (see Table A.6). This suggests that a more comprehensive engagement with new scientific knowledge is needed for scientific impact to have an influence on academic engagement. Finally, substituting mentions in print media with those in online media still does not result in the social impact being significantly associated with any mode of university-industry interaction (see Table A.7).

Another check is related to the idea that commercial organizations may not engage in the screening and sourcing of scientific knowledge from the entire higher education sector, but rather focus their efforts on the knowledge produced by a narrower group of elite universities. The assumption here is that their scientific discoveries and technical advances may have higher commercial potential. Elite universities may also rely less on signaling their scientific knowledge or attracting attention, instead prioritizing the selection of the best industry partners who are well known in scientific and business communities (Kitagawa *et al.*, 2016). As a result, the suggested signaling approach to communicating the availability and value of scientific knowledge may be more relevant to non-elite universities who may not be able to leverage their reputation when interacting with prospective industry partners. To explore this idea, we divide our sample into two sub-samples: Russell Group universities and other universities. In the UK, the term "Russell Group" encompasses 24 public research-intensive universities known for their research focus and reputation for scientific achievement, including such institutions as the University of Oxford, the University of Cambridge, and Imperial College London, among others.[18] The results of this check (see Table A.8) support the aforementioned idea by revealing that the association between scientific impact and the intensity of university-industry interaction is primarily driven by non-Russell Group universities. This finding holds true for the link between economic impact and the intensity of collaborative research as well.

It is important to note that our empirical analysis encompasses a substantial number of variables, with multiple significance tests being conducted. Hence, there is a potential risk of obtaining false positive results, where a test erroneously indicates a significant effect even if no true effect exists. To address this concern, we experimented with Bonferroni and Šidák p-value correction methods (Abdi, 2007). These methods are designed to help mitigate the potential challenges associated with false positive results. Our analysis using these correction methods produced results (available from the authors upon request) that are comparable to our baseline findings. There was no change in the set of coefficients that were significant, and only slight changes occurred in the actual level of significance. Thus, the overall interpretation of our key findings remained unchanged. Finally, our examination of correlation coefficients indicates no significant issues of multicollinearity, further supporting the validity of our analysis.

5. DISCUSSION AND CONCLUSION

5.1. Study summary

Our study draws from signaling theory to propose that university-industry interaction is a process characterized by asymmetric information regarding the availability and value of the scientific knowledge produced by universities. In order to discover and evaluate its commercial potential, commercial organizations may employ integrative search strategies that combine their internal expertise with the external expertise sourced from university-generated knowledge. The execution of these strategies is, however, complicated by the communications gap that arises

[18] For the full list of Russell Group universities, see https://russellgroup.ac.uk/about/our-universities/.

from discernable differences in the organizational and commercial logics between universities and commercial organizations, as well as the geographical and cognitive distances separating both parties. Therefore, we argue that a potential solution to bridge this communications gap is for universities to carefully consider not only how they signal the availability and value of their scientific knowledge but also the channels they utilize in order to transmit this signal. By doing so, universities may assist prospective industry partners in effectively screening the scientific knowledge they generate and, thus, facilitate productive and mutually beneficial interaction.

Our theorizing concentrates on three main types of signals, each of which is transmitted through a dedicated channel: (1) signals to members of scientific communities sent via scientific outlets; (2) signals to economic agents sent via patents; and (3) signals to members of society at large sent via media outlets. The strength of a signal is captured by the amount of attention it is able to attract and takes the form of scientific, economic, and social impact, respectively. The signal's strength is also affected by the characteristics of the intermediary transmitting this signal (e.g., scientific communities, patent offices, and media outlets). These intermediaries are crucial for the overall success of the signaling process because, as credible, independent, and mutually recognized institutions, they can act as arbiters of the quality of the knowledge generated by universities and, thus, reduce the search and transaction costs of academic engagement.

Using statistical data from UK universities, we examine three popular modes of academic engagement: collaborative research, contract research, and consultancy activities. Our findings reveal that universities with a weaker scientific impact are associated with a higher intensity of academic engagement across all three modes when they transmit this impact via more prominent scientific outlets. Conversely, among universities with a stronger scientific impact, we observe a higher intensity of academic engagement in those transmitting the impact via less prominent scientific outlets. Furthermore, we reveal that universities with a stronger economic impact show a higher intensity of collaborative research; yet, economic impact is found to have no significant association with the intensity of income from contract research or consultancy activities. Finally, our empirical analysis does not provide evidence of an association between universities' social impact and the intensity of academic engagement, regardless of the prominence of the channels through which this impact is transmitted. In what follows, we discuss the implications of these findings for both practice and policy.

5.2. Implications for practice and policy

Firstly, the results of our study offer a more nuanced perspective on the observed decline in investment in basic science by commercial organizations. This withdrawal from basic science relates to "a decline in the private value of research activities, even though scientific knowledge itself remains important for corporate invention" (Arora *et al.*, 2018, p.3). From this viewpoint, our findings suggest that bridging the persistent communications gap between universities and commercial organizations is now more critical and timely than ever, given that this declining trend began over three decades ago. For university administrators responsible for knowledge transfer efforts, our empirical analysis highlights the need for *a re-evaluation of the incentives for publication*. Specifically, our results show that to facilitate university-industry interaction, a university's scientific impact must align with the prominence of the scientific outlets through which this impact is communicated. This is in contrast with the prevailing practice of primarily focusing on publishing in highly-ranked outlets that are often less industry-oriented. To unlock the commercial value of theoretical (basic) upstream research, *especially from less renowned higher education institutions*, university administrators may encourage communication through less prominent channels that are more accessible and visible to downstream application partners when their academic researchers are able to generate a higher scientific impact. That said, we acknowledge that such a shift in publication incentives must be understood and supported by academic researchers themselves, as their personal goals and career considerations may impede this shift (Salandra *et al.*, 2022; Salter *et al.*, 2017; Van Fleet *et al.*, 2000). As Dowling (2015, p.4) points out, "[t]he perception that collaborating with industry, or spending time in industry, is damaging to an academic career path persists and detracts from the attractiveness of such activities for academics."

Secondly, when developing academic engagement policies, university administrators should be aware of *a potential downside related to economic impact*. Although our baseline results do not reveal a statistically significant association between economic impact (measured by the number of citations received by universities' scientific publications from patents) and the intensity of income from contract research and consultancy activities, our robustness checks point to a possible negative association. Hence, these specific forms of academic engagement may be hindered by improvements in science communication and the enhanced discoverability of university-generated scientific knowledge, with patent offices consequently integrating more of that knowledge into their invention assessment process (Marx and Fuegi, 2020). One plausible explanation is that higher economic impact may result in a greater accessibility of university-generated scientific knowledge to rivals, leading to knowledge spillovers. This may reduce the attractiveness of acquiring it for prospective industry partners (Arora *et al.*, 2021) and, relatedly, diminish the intensity of university-led contract research and consultancy activities. Another plausible explanation is that there is a substitution effect between academic engagement and academic entrepreneurship (Barbieri *et al.*, 2018). This implies that universities with a stronger emphasis on patenting may promote entrepreneurial activities among their staff, potentially at the expense of academic engagement. In addition, it is important to note that certain types of university-generated knowledge are protected and distributed through copyrighted software or material transfer agreements for biological samples and chemical compounds (Hemmatian *et al.*, 2022). Although not patented, these knowledge types have the potential for significant impact, which is not captured by our patent-based measure.

Thirdly, the absence of a statistically significant association between social impact and the intensity of university-industry interaction should encourage decision-makers in academic institutions to *re-evaluate their priorities and reconsider the use of media outlets as a means to engage with external stakeholders*. Evidently, "[d]espite considerable attention, the university sector remains difficult to navigate for business" (NCUB, 2022). Placing a greater emphasis on media outlets to enhance the visibility of university-generated scientific knowledge is clearly a promising strategy, supported by initial evidence indicating that the media coverage of spin-off activities can bolster a university's research income (Pitsakis *et al.*, 2015). Hence, exploring specific media outlets that can enhance the discoverability of university-generated knowledge is essential. Understanding how to effectively communicate this knowledge to prospective industry partners, including by incorporating media-based dissemination into research projects (Marín-González *et al.*, 2017) is an emerging avenue for further investigation and analysis. It should be recognized, however, that media outlets are mainly viewed and serve as a means to communicate the availability and value of university-generated knowledge to non-academic audiences, rather than a direct mechanism for increasing academic engagement. Nevertheless, as our conceptual framework suggests, media outlets, if strategically used, can provide universities with a valuable communication channel that has the potential to enhance university-industry interaction.

Fourthly, for corporate leaders and R&D managers, our research highlights the increasing importance of *developing and refining knowledge screening skills*. As stated by Fontana *et al.* (2006, p.321), "larger firms with higher learning abilities, and which engage in in-depth screening activities are the most likely partners for universities." Recognizing the aforementioned decline in private investment in basic science, industrial scientists face a growing need to swiftly triage and assess valuable scientific knowledge as it emerges from academic researchers. The speed of screening becomes crucial in this context due to the public good nature of university-generated knowledge; hence, organizations that can discover it first stand to gain greater benefits from its commercial utilization. One potential approach to developing these skills within the industrial setting is to adopt more flexible employment practices that allow industry scientists to maintain dual affiliations spanning both university and corporate labs. By doing so, corporate leaders and R&D managers need to recognize the divergent organizational and commercial logics, which can complicate communication and interaction between their organizations and universities. This challenge can be addressed by establishing different goals and priorities for research projects conducted jointly with universities, as well as encompassing a longer time horizon, a higher tolerance for failure, and opportunities for knowledge sharing, among other factors.

Fifthly, for public administrators and policymakers, our study offers *a holistic framework for understanding and organizing science communication* in a manner that benefits university-industry interaction. More specifically, our findings suggest that allocating a portion of public investment toward developing and enhancing the external signaling capabilities of universities may result in a higher intensity of academic engagement. One promising avenue for amplifying the intended effects of public investment on the private sector may involve *investing in science communication programs and initiatives* that emphasize the construction of clear narratives and the persuasive power of storytelling (Green *et al.*, 2018; Martinez-Conde and Macknik, 2017). The response to the initial outbreak and the aftermath of the COVID-19 global pandemic further underscores the significance of science communication and the increasing need for universities to augment their external signaling capabilities to quickly reach broader audiences with well-composed, reliable messages (Saitz and Schwitzer, 2020). By aiding universities in effectively communicating their scientific discoveries and technical advances to commercial organizations, public administrators and policymakers can contribute to altering the prevailing perception of the practical value inherent in university-generated knowledge. As corporate leaders and R&D managers become more cognizant of this value, despite its public good nature, they may be more inclined to invest in research activities that produce such goods, thereby supplementing public sector funding with financial resources from the private sector.

Finally, in line with our conceptual framework, it is essential for university administrators and policymakers to recognize *the vital role played by intermediary organizations in supporting the communication of scientific discoveries and technical advances*. Each stakeholder should fulfill their responsibilities to safeguard the integrity of these intermediaries, as any compromise in this respect may undermine the credibility of science communication as a whole and, more specifically, have negative implications for university-industry interaction. Going back to our earlier example of the COVID-19 global pandemic, the rapid dissemination of research during that period exposed significant challenges in the communication of scientific findings. One of the main concerns was the potential for spreading unverified and unreliable information, which not only compromised the accuracy of the information shared but also eroded public trust in the scientific knowledge generated by universities (Bagdasarian *et al.*, 2020). With a significant surge in the volume of publications across scientific and media outlets, it is inevitable that the standards of research production and dissemination will face hurdles (Martin, 2013). This trend may have an adverse effect on academic engagement due to decreased efficiency in the science communication system as search and transaction costs increase.

5.3. Limitations and directions for future research

Our study has some limitations that present opportunities for future research. *Firstly,* our conceptual framework primarily focuses on university-level signaling and does not explore how individual researchers employ signaling strategies, often outside formal university channels, to foster their interaction with commercial organizations. Individual-level engagement, such as networking, has proven to be important in certain fields, as it may enable effective knowledge transfer (Perkmann *et al.*, 2015; Bodas Freitas *et al.*, 2013). Hence, in these fields, relying solely on university-wide channels may not contribute as much to the intensity of academic engagement as anticipated. Future research could explore and test the conceptual framework proposed in our study at the individual level and across different fields to deepen our understanding of the impact of information asymmetries and the communications gap on university-industry interaction. *Secondly*, we test our theoretical propositions within the UK higher education context. However, it is important to acknowledge that there exist significant variations among countries not only in their priorities regarding knowledge transfer from academia to industry but also in the specific forms through which this transfer takes place (Wright, 2007). Conducting further investigations in other empirical settings and across various countries could, therefore, provide more nuanced insights and determine the generalizability of the patterns we have uncovered. *Thirdly*, a crucial contextual factor that may shape academic engagement is the role of government as a catalyst for university-industry interaction (Johnson *et al.*, 2022; Lanahan *et al.*, 2021). A number of studies have examined the influence of public sector R&D expenditure on research activities. These studies focus on the role of public funding in driving industrial innovation (Mansfield, 1991), including the effects of public R&D subsidies and grants (Gullec and Van Pottelsberghe de la Potterie, 2003; Hottentrott and Lawson, 2014; Joshi *et al.*, 2018; Lanahan *et al.*, 2022; Link and Scott, 2012) and the degree of complementarity or substitutability between public and private sector R&D funding (Leyden and Link, 1991; David and Hall, 2000; Muscio *et al.*, 2013). Expanding this line of inquiry to study the combination of signals and communication channels utilized by recipients of public sector R&D funding could present a promising avenue for future research.[19] *Finally*, in our empirical analysis, we rely on pre-sample information to account for unobserved heterogeneity across universities (Blundell *et al.*, 1999). Despite our efforts, we are unable to completely eliminate the possibility that some unobserved heterogeneity, which may influence our results, still exists. Future research may explore this issue further, with the aim of establishing the causality of the identified associations.

[19] We thank an anonymous reviewer for suggesting this avenue for future research.

Recalling Mokyr's (2002) assertion on the importance of both understanding and locating knowledge, we believe that minding the persistent communications gap in academic engagement remains a salient issue that demands the attention of scholars, managers, and policymakers.

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Figure 1. Typology of signals by the channels of transmission

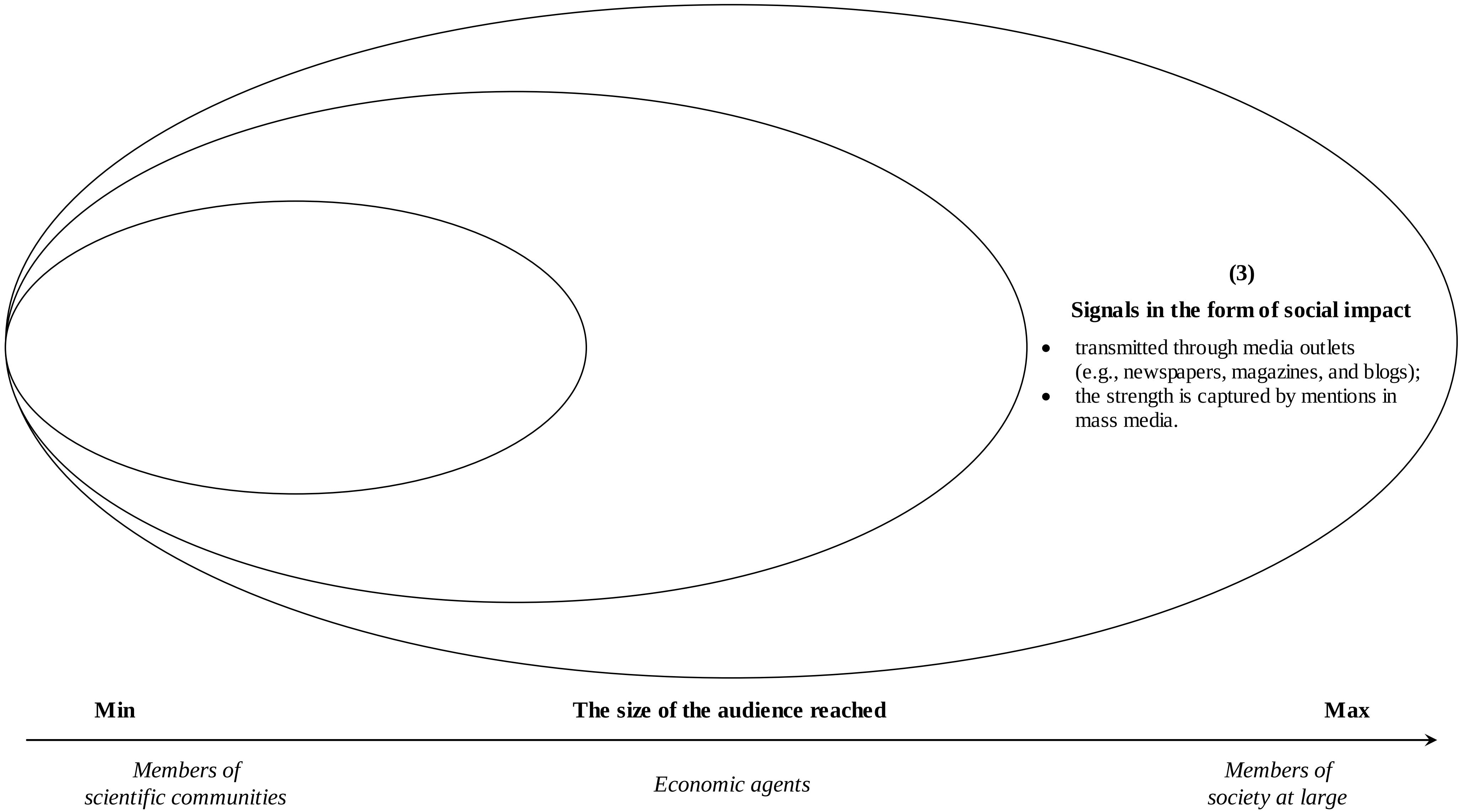


Figure 2. Conceptual framework

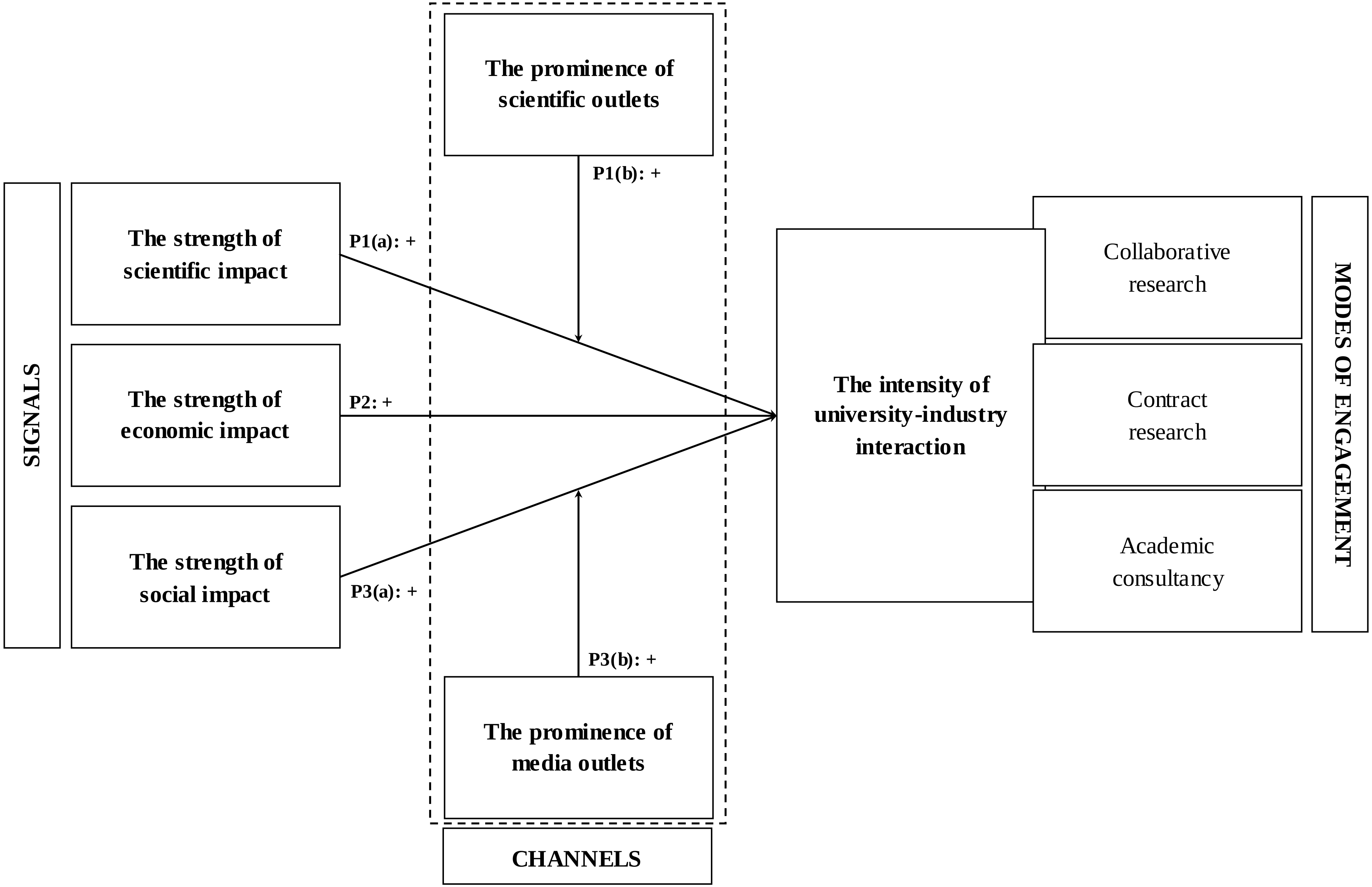
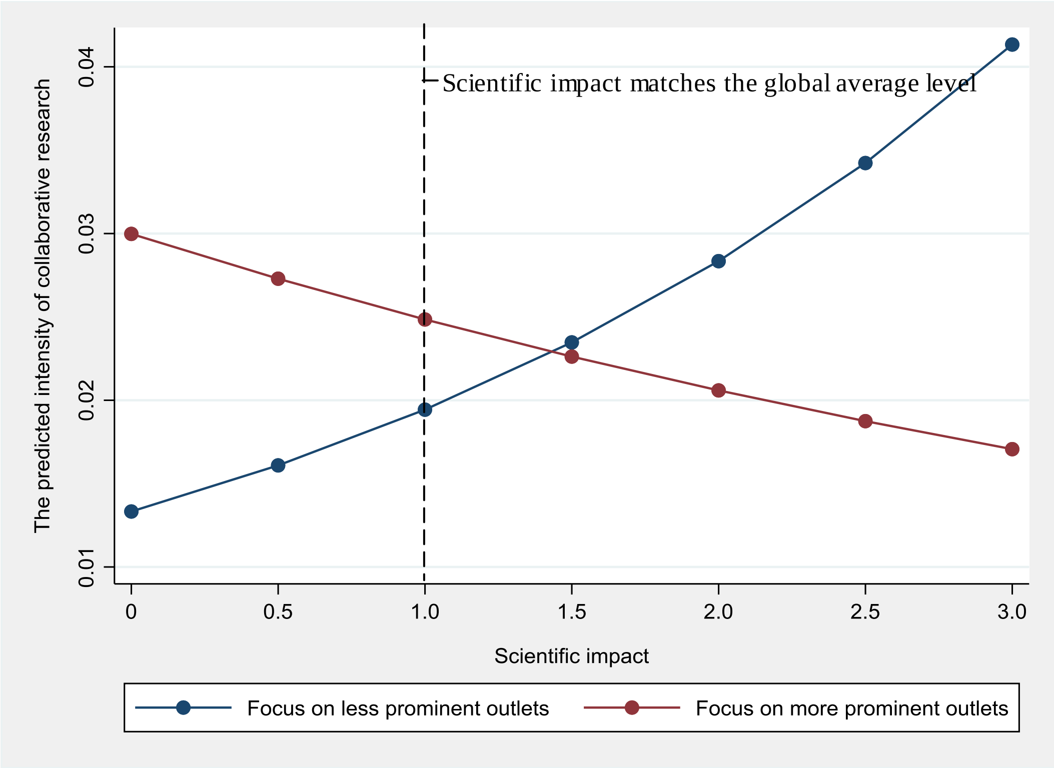
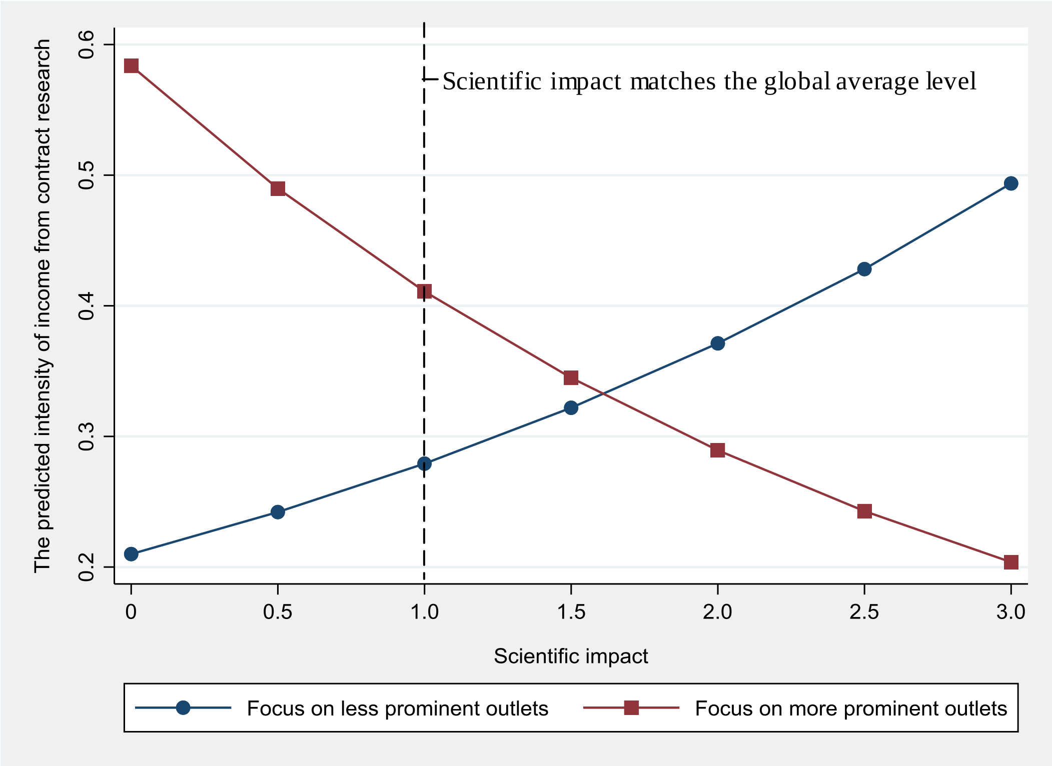


Figure 3. Interaction effects between the scientific impact and the prominence of scientific outlets on the intensity of collaborative research



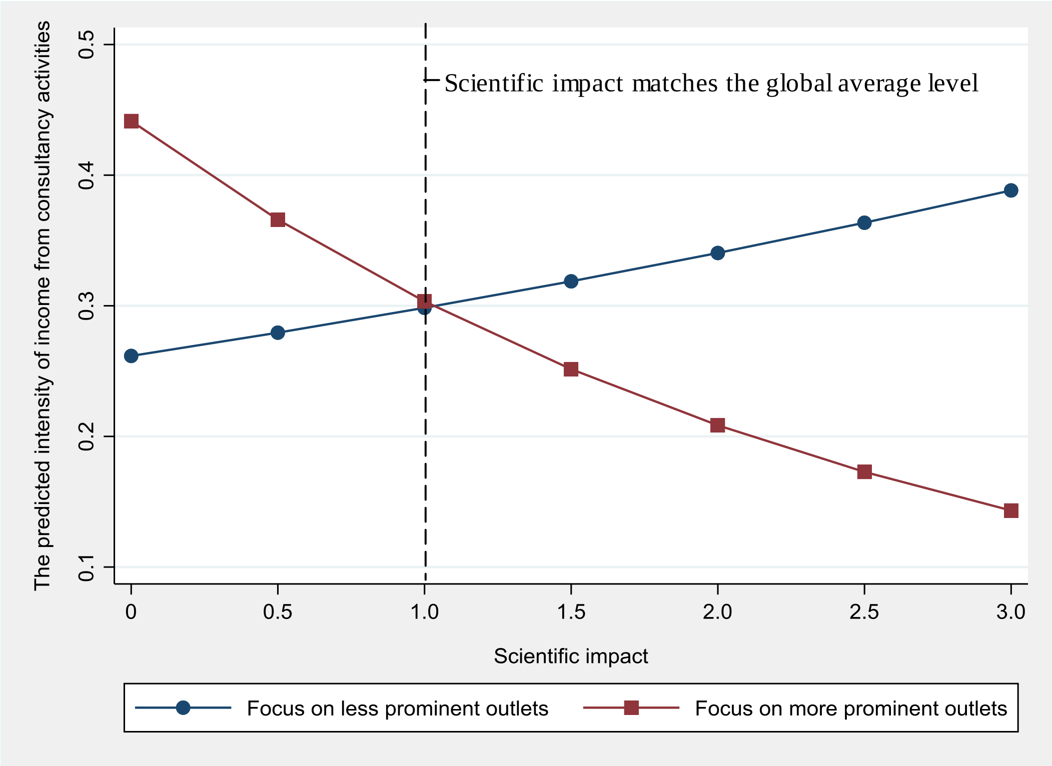
Note: The results are based on *Model 8*. A lower prominence of scientific outlets is set at the first quartile level, while a higher prominence is set at the third quartile level. The predicted values have been exponentiated. The exact marginal effects and their significance levels are presented in Table A.3.a in the Online Appendix.

Figure 4. Interaction effects between the scientific impact and the prominence of scientific outlets on the intensity of income from contract research



Note: The results are based on *Model 16*. A lower prominence of scientific outlets is set at the first quartile level, while a higher prominence is set at the third quartile level. The predicted values have been exponentiated. The exact marginal effects and their significance levels are presented in Table A.3.b in the Online Appendix.

Figure 5. Interaction effects between the scientific impact and the prominence of scientific outlets on the intensity of income from consultancy activities



Note: The results are based on *Model 24*. A lower prominence of scientific outlets is set at the first quartile level, while a higher prominence is set at the third quartile level. The predicted values have been exponentiated. The exact marginal effects and their significance levels are presented in Table A.3.c in the Online Appendix.

Table 1. Potential sources of the communications gap between universities and commercial organizations

Potential sources of the communications gap	Description from each perspective		Representative studies
	Universities	Commercial organizations	
Organizational logic			
Research focus	Focus on theoretical upstream research (basic science)	Focus on practical downstream research (applied science)	Gulbrandsen and Smeby, 2005; Thursby and Thursby, 2002; Trajtenberg *et al.*, 1997; Van Looy *et al.*, 2004; Van Looy *et al.*, 2006; West, 2008
Incentives for staff	Career incentives for academic researchers (e.g., tenure, promotion, and recognition)	Financial incentives for industry scientist (e.g., royalties, bonuses, and stock options)	Azoulay *et al.*, 2011; Ederer and Manso, 2011; Jessani *et al.*, 2020; Manso, 2011; Merton, 1957; Sormani *et al.*, 2022; Ward and Dranove, 1995
Stakeholder groups	Diverse stakeholder groups with weaker oversight and broader governance authority	Concentrated stakeholders with stronger oversight and narrower governance authority	Jongbloed *et al.*, 2008; McCann *et al.*, 2022; Miller *et al.*, 2014; Radko *et al.*, 2022
Time horizon	Longer time horizon due to a lower susceptibility to marker forces	Shorter time horizon due to a higher susceptibility to marker forces	Bjerregaard, 2010; Borah and Ellwood, 2022; Mannak *et al.*, 2019; Santoro and Chakrabarti, 1999
Commercial logic			
Mandated mission	Non-profit mission to serve the public interest as non-profit educational institutions	For-profit mission to deliver value to their target markets as for-profit enterprises	Argyres and Liebeskind, 1998; Lacetera, 2009; Masten, 2006; Merton, 1973; Scott, 2006
Priorities of staff	Internal search for interesting ideas without fully considering their commercial viability	External search for interesting ideas that seem to be commercially viable	Laursen and Salter, 2004; Laursen and Salter, 2006; Link *et al.*, 2007; Siegel *et al.*, 2003; 2004
Knowledge sharing	Reward knowledge dissemination and disclosure	Reward knowledge appropriation and protection	Merton, 1973; Nelson, 1959; Nelson , 2001; Pisano, 2006; Teece, 1986
Market awareness	Lower as they are focused on creating new scientific knowledge as a public good	Higher as they are focused on using scientific knowledge to compete in the market	Colyvas *et al.*, 2002; Czarniawska and Genell, 2002; Elfenbein, 2007; Geuna and Muscio, 2009; Nelson, 2004
Distance			
Geographical distance	A shorter geographical distance between universities and commercial organizations may foster bidirectional knowledge spillovers via increased face-to-face contacts and joint research		Abramovsky and Simpson, 2011; Audretsch and Feldman, 2004; Belenzon and Schankerman, 2013; Bikard and Marx, 2020; Bishop *et al.*, 2011; D'Este *et al.*, 2013; Laursen *et al.*, 2011; Ponds *et al.*, 2007
Cognitive distance	A shorter cognitive distance between universities and commercial organizations may ease collaboration between them due to lower communication and coordination costs		Crescenzi *et al.*, 2016; Muscio and Pozzali, 2013; Kotha *et al.*, 2013; Nooteboom *et al.*, 2007; Villani *et al.*, 2017

Table 2. Descriptive statistics

No.	Variables	Mean	SD	Min	Max
1	ACADCOLRES $_{i,t}$	0.04	0.03	0.00	0.15
2	ACADCONTRES $_{i,t}$	1.94	3.26	0.00	34.41
3	ACADCONSULT $_{i,t}$	1.52	5.65	0.00	78.07
4	IMPSCI $_{i,t}$	1.54	0.55	0.00	6.71
5	IMPECON $_{i,t}$	19.65	32.77	0.00	319.10
6	IMPSOC $_{i,t}$	1.31	1.00	0.00	10.18
7	PROMJOURN $_{i,t}$	32.76	11.12	0.00	100.00
8	PROMMEDIA $_{i,t}$	0.72	0.23	0.00	1.00
9	HEPSIZE $_{i,t}$	9.46	0.85	5.08	12.21
10	HEPPOLY $_{i}$	0.29	0.46	0.00	1.00
11	HEPPATAR $_{i,t}$	0.50	0.21	0.00	1.00
12	HEPCOMSTRAT $_{i,t}$	4.17	0.85	1.00	5.00
13	HEPINCENT $_{i,t}$	3.74	0.82	1.00	5.00
14	HEPTTOEXP $_{i,t}$	18.13	9.30	0.00	50.00
15	HEPRESAC $_{i,t}$	0.73	0.19	0.00	1.00
16	HEPRESQUAL $_{i}$	2.24	0.44	1.08	3.35
17	HEPPUBL $_{i,t}$	1,224.21	1,997.60	1.00	13,384.00

Note: To enhance interpretability, variables 1–3 in this table are displayed prior to the application of a logarithmic transformation. Variables 2 and 3 have been scaled based on the total number of academic staff (FTEs).

Table 3. Correlation matrix

No.	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	ACADCOLRES $_{i,t}$	1.000																
2	ACADCONTRES $_{i,t}$	**0.586**	1.000															
3	ACADCONSULT $_{i,t}$	**0.490**	**0.594**	1.000														
4	IMPSCI $_{i,t}$	**0.428**	**0.423**	**0.325**	1.000													
5	IMPECON $_{i,t}$	**0.177**	**0.282**	**0.209**	**0.269**	1.000												
6	IMPSOC $_{i,t}$	**0.199**	**0.135**	**0.190**	**0.218**	**0.071**	1.000											
7	PROMJOURN $_{i,t}$	**0.531**	**0.541**	**0.378**	**0.587**	**0.305**	**0.241**	1.000										
8	PROMMEDIA $_{i,t}$	**0.321**	**0.262**	**0.194**	**0.218**	0.039	**-0.109**	**0.279**	1.000									
9	HEPSIZE $_{i,t}$	**0.481**	**0.467**	**0.364**	**0.201**	**0.131**	0.013	**0.202**	**0.274**	1.000								
10	HEPPOLY $_{i}$	**0.102**	-0.032	**0.076**	**-0.164**	**-0.165**	-0.029	**-0.268**	0.046	**0.286**	1.000							
11	HEPPATAR $_{i,t}$	0.012	**0.097**	**-0.071**	**0.082**	**0.113**	0.049	**0.064**	0.037	0.003	0.057	1.000						
12	HEPCOMSTRAT $_{i,t}$	**0.440**	**0.539**	**0.535**	**0.383**	**0.338**	0.045	**0.456**	**0.095**	**0.116**	**-0.100**	**0.097**	1.000					
13	HEPINCENT $_{i,t}$	**0.231**	**0.176**	**0.167**	**0.105**	0.014	**0.114**	**0.108**	-0.009	**0.177**	0.030	**0.111**	**0.104**	1.000				
14	HEPTTOEXP $_{i,t}$	**0.311**	**0.246**	**0.281**	**0.212**	**0.086**	**0.156**	**0.297**	**0.098**	**0.188**	**-0.106**	-0.032	**0.212**	**0.350**	1.000			
15	HEPRESAC $_{i,t}$	**0.301**	**0.321**	**0.252**	**0.133**	0.006	0.051	**0.251**	**0.114**	**0.310**	**0.111**	-0.013	**0.212**	-0.030	**0.189**	1.000		
16	HEPRESQUAL $_{i}$	**0.582**	**0.517**	**0.409**	**0.565**	**0.338**	**0.258**	**0.710**	**0.403**	**0.343**	**-0.238**	0.016	**0.329**	**0.112**	**0.350**	**0.276**	1.000	
17	HEPPUBL $_{i,t}$	**0.324**	**0.429**	**0.267**	**0.448**	**0.315**	**0.122**	**0.527**	**0.232**	**0.359**	**-0.265**	**0.217**	**0.417**	**0.085**	**0.174**	**0.233**	**0.581**	1.000

Note: The table displays Pearson's pairwise correlation coefficients for the variables used in this study. The correlation coefficients highlighted in bold indicate significance at the 5% level or higher. All dependent variables (1–3) have undergone a logarithmic transformation. Prior to the transformation, variables 2 and 3 were scaled using the total number of academic staff (FTEs). In cases where the variables had a value of zero, we added 0.0001 before calculating the natural logarithm.

Table 4. Results for the intensity of collaborative research

Explanatory variables	Dependent variable = ACADCOLRES $_{i,t}$							
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*	*Model 7*	*Model 8*
IMPSCI $_{i,t-1}$		**0.245***			**0.233***	**1.141*****	**0.240***	**1.165*****
		(0.136)			*(0.137)*	*(0.358)*	*(0.137)*	*(0.354)*
IMPECON $_{i,t-1}$			**0.0032****		**0.0029****	**0.0027***	**0.0029****	**0.0028***
			(0.0014)		*(0.0014)*	*(0.0014)*	*(0.0014)*	*(0.0015)*
IMPSOC $_{i,t-1}$				-0.078	-0.076	-0.063	-0.049	-0.048
				(0.058)	*(0.058)*	*(0.060)*	*(0.148)*	*(0.144)*
PROMJOURN $_{i,t-1}$						**0.048*****		**0.048*****
						(0.018)		*(0.017)*
IMPSCI $_{i,t-1}$ × PROMJOURN $_{i,t-1}$						**-0.033*****		**-0.033*****
						(0.011)		*(0.011)*
PROMMEDIA $_{i,t-1}$							0.621	0.617
							(0.554)	*(0.554)*
IMPSOC $_{i,t-1}$ × PROMMEDIA $_{i,t-1}$							-0.005	0.017
							(0.193)	*(0.189)*
HEPSIZE $_{i,t-1}$	**0.612*****	**0.614*****	**0.600*****	**0.606*****	**0.597*****	**0.533*****	**0.561*****	**0.495*****
	(0.100)	*(0.099)*	*(0.102)*	*(0.102)*	*(0.103)*	*(0.109)*	*(0.089)*	*(0.097)*
HEPPOLY $_{i}$	**0.414*****	**0.422*****	**0.445*****	**0.424*****	**0.459*****	**0.432*****	**0.460*****	**0.431*****
	(0.135)	*(0.137)*	*(0.136)*	*(0.139)*	*(0.141)*	*(0.138)*	*(0.141)*	*(0.139)*
HEPPATAR $_{i,t-1}$	**2.180*****	**2.010*****	**1.977*****	**2.137*****	**1.797*****	**1.908*****	**1.811*****	**1.939*****
	(0.419)	*(0.421)*	*(0.389)*	*(0.431)*	*(0.409)*	*(0.448)*	*(0.394)*	*(0.426)*
HEPCOMSTRAT $_{i,t-1}$	**0.119***	**0.118***	**0.132****	**0.122***	**0.133****	**0.119***	**0.128***	**0.114***
	(0.067)	*(0.068)*	*(0.067)*	*(0.067)*	*(0.068)*	*(0.067)*	*(0.066)*	*(0.065)*
HEPINCENT $_{i,t-1}$	0.053	0.050	0.054	0.054	0.052	0.059	0.049	0.056
	(0.064)	*(0.063)*	*(0.064)*	*(0.065)*	*(0.063)*	*(0.062)*	*(0.062)*	*(0.062)*
HEPTTOEXP $_{i,t-1}$	0.0030	0.0047	0.0029	0.0028	0.0043	0.0020	0.0041	0.0018
	(0.0052)	*(0.0053)*	*(0.0051)*	*(0.0053)*	*(0.0053)*	*(0.0053)*	*(0.0052)*	*(0.0051)*
HEPRESAC $_{i,t-1}$	0.152	0.103	0.087	0.178	0.073	0.100	0.040	0.069
	(0.387)	*(0.392)*	*(0.388)*	*(0.383)*	*(0.386)*	*(0.386)*	*(0.372)*	*(0.372)*
HEPRESQUAL $_{i}$	**1.748*****	**1.575*****	**1.667*****	**1.805*****	**1.569*****	**1.641*****	**1.472*****	**1.553*****
	(0.226)	*(0.246)*	*(0.237)*	*(0.227)*	*(0.249)*	*(0.273)*	*(0.241)*	*(0.265)*
HEPPUBL $_{i,t-1}$	**-0.0002*****	**-0.0002*****	**-0.0002*****	**-0.0002*****	**-0.0002*****	**-0.0001*****	**-0.0002*****	**-0.0001*****
	(0.0000)	*(0.0000)*	*(0.0000)*	*(0.0000)*	*(0.0000)*	*(0.0000)*	*(0.0000)*	*(0.0000)*
HEP fixed effects	**10.814*****	**11.875*****	**11.068*****	**10.760*****	**11.988*****	**10.051****	**11.717*****	**9.770*****
	(3.725)	*(3.713)*	*(3.786)*	*(3.824)*	*(3.858)*	*(4.005)*	*(3.650)*	*(3.793)*
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-sq: between/overall	0.85/0.59	0.85/0.59	0.85/0.59	0.84/0.59	0.85/0.60	0.85/0.61	0.85/0.60	0.85/0.61
Number of clusters	133	133	133	133	133	133	133	133
Number of observations	1,064	1,064	1,064	1,064	1,064	1,064	1,064	1,064

* 10% significance; ** 5% significance; *** 1% significance. Standard errors (in parentheses) are clustered at the HEP level. The constant is included in all models but is not reported.

Note: The dependent variable is log-transformed. When calculating the natural logarithm of variables with a value of zero, we added 0.0001. HEP fixed effects are based on the five-year (2006–2010) pre-sample average of the dependent variable (see Blundell *et al*., 1999).

Table 5. Results for the intensity of income from contract research

Explanatory variables	Dependent variable = ACADCONTRES $_{i,t}$							
	Model 9	*Model 10*	*Model 11*	*Model 12*	*Model 13*	*Model 14*	*Model 15*	*Model 16*
IMPSCI $_{i,t-1}$		0.183			0.179	**1.140****	0.189	**1.171****
		(0.226)			*(0.223)*	*(0.517)*	*(0.228)*	*(0.523)*
IMPECON $_{i,t-1}$			0.0007		0.0006	0.0003	0.0008	0.0005
			(0.0017)		*(0.0016)*	*(0.0016)*	*(0.0015)*	*(0.0016)*
IMPSOC $_{i,t-1}$				0.046	0.047	0.057	-0.066	-0.034
				(0.091)	*(0.091)*	*(0.087)*	*(0.196)*	*(0.185)*
PROMJOURN $_{i,t-1}$						**0.061*****		**0.060*****
						(0.022)		*(0.023)*
IMPSCI $_{i,t-1}$ × PROMJOURN $_{i,t-1}$						**-0.037****		**-0.037****
						(0.015)		*(0.015)*
PROMMEDIA $_{i,t-1}$							0.442	0.464
							(0.526)	*(0.507)*
IMPSOC $_{i,t-1}$ × PROMMEDIA $_{i,t-1}$							0.248	0.211
							(0.250)	*(0.238)*
HEPSIZE $_{i,t-1}$	**1.049*****	**1.043*****	**1.048*****	**1.050*****	**1.043*****	**1.060*****	**1.017*****	**1.032*****
	(0.315)	*(0.315)*	*(0.313)*	*(0.316)*	*(0.315)*	*(0.316)*	*(0.316)*	*(0.317)*
HEPPOLY $_{i}$	0.038	0.046	0.047	0.034	0.050	-0.016	0.052	-0.017
	(0.377)	*(0.378)*	*(0.376)*	*(0.377)*	*(0.377)*	*(0.366)*	*(0.379)*	*(0.368)*
HEPPATAR $_{i,t-1}$	**4.803*****	**4.698*****	**4.742*****	**4.829*****	**4.675*****	**4.685*****	**4.721*****	**4.750*****
	(1.432)	*(1.442)*	*(1.430)*	*(1.427)*	*(1.437)*	*(1.379)*	*(1.404)*	*(1.350)*
HEPCOMSTRAT $_{i,t-1}$	-0.151	-0.151	-0.147	-0.151	-0.148	-0.158	-0.150	-0.157
	(0.185)	*(0.185)*	*(0.185)*	*(0.185)*	*(0.185)*	*(0.187)*	*(0.184)*	*(0.186)*
HEPINCENT $_{i,t-1}$	-0.009	-0.011	-0.008	-0.008	-0.010	-0.004	-0.014	-0.009
	(0.160)	*(0.161)*	*(0.160)*	*(0.160)*	*(0.161)*	*(0.157)*	*(0.159)*	*(0.154)*
HEPTTOEXP $_{i,t-1}$	**0.0364***	**0.0378***	**0.0364***	**0.0366***	**0.0380***	0.0335	**0.0372***	0.0329
	(0.0210)	*(0.0212)*	*(0.0210)*	*(0.0210)*	*(0.0213)*	*(0.0205)*	*(0.0209)*	*(0.0201)*
HEPRESAC $_{i,t-1}$	0.863	0.822	0.845	0.843	0.788	0.735	0.793	0.739
	(0.594)	*(0.598)*	*(0.604)*	*(0.606)*	*(0.620)*	*(0.627)*	*(0.627)*	*(0.635)*
HEPRESQUAL $_{i}$	**2.115*****	**2.014*****	**2.081*****	**2.082*****	**1.954*****	**1.840****	**1.783****	**1.698****
	(0.687)	*(0.699)*	*(0.691)*	*(0.693)*	*(0.714)*	*(0.721)*	*(0.705)*	*(0.721)*
HEPPUBL $_{i,t-1}$	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0000	-0.0001	-0.0000
	(0.0001)	*(0.0001)*	*(0.0001)*	*(0.0001)*	*(0.0001)*	*(0.0001)*	*(0.0001)*	*(0.0001)*
HEP fixed effects	**0.014*****	**0.014*****	**0.014*****	**0.014*****	**0.014*****	**0.015*****	**0.014*****	**0.015*****
	(0.004)	*(0.004)*	*(0.004)*	*(0.004)*	*(0.004)*	*(0.005)*	*(0.004)*	*(0.004)*
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-sq: between/overall	0.67/0.55	0.67/0.55	0.67/0.55	0.67/0.55	0.67/0.55	0.68/0.57	0.67/0.56	0.68/0.57
Number of clusters	133	133	133	133	133	133	133	133
Number of observations	1,064	1,064	1,064	1,064	1,064	1,064	1,064	1,064

* 10% significance; ** 5% significance; *** 1% significance. Standard errors (in parentheses) are clustered at the HEP level. The constant is included in all models but is not reported.

Note: The dependent variable is log-transformed. When calculating the natural logarithm of variables with a value of zero, we added 0.0001. HEP fixed effects are based on the five-year (2006–2010) pre-sample average ratio of the total income from research grants and contracts to the total number of academic staff (see Blundell *et al.*, 1999).

Table 6. Results for the intensity of income from consultancy activities

Explanatory variables	Dependent variable = ACADCONSULT $_{i,t}$							
	Model 17	*Model 18*	*Model 19*	*Model 20*	*Model 21*	*Model 22*	*Model 23*	*Model 24*
IMPSCI $_{i,t-1}$		-0.001			0.010	**0.830****	0.012	**0.838****
		(0.132)			*(0.137)*	*(0.361)*	*(0.137)*	*(0.369)*
IMPECON $_{i,t-1}$			-0.0018		-0.0019	-0.0016	-0.0019	-0.0017
			(0.0019)		*(0.0019)*	*(0.0019)*	*(0.0019)*	*(0.0019)*
IMPSOC $_{i,t-1}$				-0.057	-0.061	-0.045	-0.023	-0.013
				(0.083)	*(0.083)*	*(0.077)*	*(0.173)*	*(0.167)*
PROMJOURN $_{i,t-1}$						**0.031****		**0.031****
						(0.014)		*(0.014)*
IMPSCI $_{i,t-1}$ × PROMJOURN $_{i,t-1}$						**-0.030*****		**-0.030*****
						(0.011)		*(0.011)*
PROMMEDIA $_{i,t-1}$							0.123	0.147
							(0.489)	*(0.508)*
IMPSOC $_{i,t-1}$ × PROMMEDIA $_{i,t-1}$							-0.063	-0.048
							(0.256)	*(0.254)*
HEPSIZE $_{i,t-1}$	**0.513****	**0.513****	**0.515****	**0.512****	**0.513****	**0.517****	**0.514****	**0.513****
	(0.228)	*(0.229)*	*(0.227)*	*(0.227)*	*(0.227)*	*(0.227)*	*(0.230)*	*(0.230)*
HEPPOLY $_{i}$	**0.697****	**0.697****	**0.675****	**0.700****	**0.679****	**0.596****	**0.672****	**0.591****
	(0.293)	*(0.294)*	*(0.292)*	*(0.294)*	*(0.294)*	*(0.292)*	*(0.292)*	*(0.291)*
HEPPATAR $_{i,t-1}$	**3.230*****	**3.227*****	**3.372*****	**3.206*****	**3.338*****	**3.525*****	**3.385*****	**3.566*****
	(1.109)	*(1.121)*	*(1.103)*	*(1.095)*	*(1.101)*	*(1.082)*	*(1.090)*	*(1.074)*
HEPCOMSTRAT $_{i,t-1}$	**0.188****	**0.188****	**0.179****	**0.188****	**0.178****	**0.171****	**0.176****	**0.169***
	(0.084)	*(0.084)*	*(0.086)*	*(0.085)*	*(0.087)*	*(0.086)*	*(0.088)*	*(0.087)*
HEPINCENT $_{i,t-1}$	0.005	0.005	0.003	0.005	0.002	0.010	0.006	0.014
	(0.079)	*(0.079)*	*(0.079)*	*(0.079)*	*(0.079)*	*(0.076)*	*(0.079)*	*(0.075)*
HEPTTOEXP $_{i,t-1}$	-0.0039	-0.0039	-0.0039	-0.0039	-0.0040	-0.0050	-0.0037	-0.0047
	(0.0128)	*(0.0127)*	*(0.0127)*	*(0.0128)*	*(0.0127)*	*(0.0125)*	*(0.0127)*	*(0.0126)*
HEPRESAC $_{i,t-1}$	-0.102	-0.100	-0.052	-0.081	-0.026	-0.103	-0.060	-0.134
	(0.611)	*(0.604)*	*(0.617)*	*(0.621)*	*(0.622)*	*(0.608)*	*(0.634)*	*(0.618)*
HEPRESQUAL $_{i}$	**1.440****	**1.441****	**1.524****	**1.481****	**1.566****	**1.702*****	**1.561****	**1.689*****
	(0.672)	*(0.667)*	*(0.695)*	*(0.672)*	*(0.686)*	*(0.663)*	*(0.680)*	*(0.659)*
HEPPUBL $_{i,t-1}$	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
	(0.0001)	*(0.0001)*	*(0.0001)*	*(0.0001)*	*(0.0001)*	*(0.0001)*	*(0.0001)*	*(0.0001)*
HEP fixed effects	**0.014*****	**0.014*****	**0.014*****	**0.013*****	**0.014*****	**0.016*****	**0.014*****	**0.016*****
	(0.005)	*(0.005)*	*(0.005)*	*(0.005)*	*(0.005)*	*(0.004)*	*(0.005)*	*(0.004)*
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-sq: between/overall	0.59/0.47	0.59/0.47	0.59/0.47	0.59/0.47	0.59/0.47	0.61/0.48	0.59/0.47	0.61/0.49
Number of clusters	133	133	133	133	133	133	133	133
Number of observations	1,064	1,064	1,064	1,064	1,064	1,064	1,064	1,064

* 10% significance; ** 5% significance; *** 1% significance. Standard errors (in parentheses) are clustered at the HEP level. The constant is included in all models but is not reported.

Note: The dependent variable is log-transformed. When calculating the natural logarithm of variables with a value of zero, we added 0.0001. HEP fixed effects are based on the five-year (2006–2010) pre-sample average ratio of the total income from research grants and contracts to the total number of academic staff (see Blundell *et al.*, 1999).

Online Appendix

Table A.1. Study variables and data sources

Name (mnemonic)	Description	Source
Dependent variables		
The intensity of collaborative research (ACADCOLRES $_{i,t}$)	The natural logarithm of the share of publications with joint academic and corporate affiliations.	SciVal
The intensity of contract research (ACADCONTRES $_{i,t}$)	The natural logarithm of the ratio between the total value of contract research (£ thousands), which includes both SMEs and non-SMEs and excludes any funds already returned in collaborative research involving public funding, and the total number of academic staff.	HESA HE-BCI: Part B, Table 1b
The intensity of consultancy activities (ACADCONSULT $_{i,t}$)	The natural logarithm of the ratio between the total value of consultancy contracts (£ thousands, which includes both SMEs and non-SMEs, to the total number of academic staff.	HESA HE-BCI: Part B, Table 2
Independent variables		
Scientific impact (IMPSCI $_{i,t}$)	The ratio between the total of citations received by publications of the HEP and the expected world average for the subject field, publication type, and publication year.	SciVal; CiteScore
Economic impact (IMPECON $_{i,t}$)	The average patent-citations received by 1,000 scholarly outputs published by the HEP.	SciVal; EPO; JPO; UK IPO; USPTO; WIPO
Social impact (IMPSOC $_{i,t}$)	The ratio between the total of mentions in printed media received by publications of the HEP and the expected world average for the subject field, publication type, and publication year.	SciVal; LexisNexis
Moderator variables		
The prominence of scientific outlets (PROMJOURN $_{i,t}$)	The share of publications of the HEP published in the top 10% of the world's most-cited journals according to CiteScore.	SciVal; CiteScore
The prominence of media outlets (PROMMEDIA $_{i,t}$)	The ratio between the number of media mentions in internationally, regionally, and nationally recognized media outlets (weighted by publication type, demographics, and audience reach) and the number of media mentions received by the selected entities' publications.	
Control variables		
HEP size (HEPSIZE $_{i,t}$)	The natural logarithm of the total number of higher education students, irrespectively of their level of study, mode of study, and domicile.	HESA Student Record: Table 1

Former polytechnic status (HEPPOLY $_{i}$)	A dummy variable that takes on the value of one if the HEP is a former polytechnic or central institution, and zero otherwise.	HEPs' official web-sites
Share of patentable subject areas (HEPPATAR $_{i,t}$)	The share of academic staff (FTEs) working in patentable subject areas (see Table A.2) among all academic staff.	HESA Staff Record: Table 13a
Strategy towards commercialization (HEPCOMSTRAT $_{i,t}$)	A variable that indicates whether the HEP has a strategic plan for business engagement. The variable is measured on a scale of 1 to 5, where 1 refers to the absence of the strategic plan, and 5 refers to that the strategic plan has been developed and implemented through an inclusive process involving the entire HEP.	HESA HE–BCI: Part A, Section 1
Incentives for staff to engage with industry (HEPINCENT $_{i,t}$)	A variable that indicates the level of incentives for staff at the HEP to engage with business and the community. The variable is measured on a scale of 1 to 5, where 1 refers to a situation where barriers outweigh any incentives offered, and 5 refers to the presence of strong incentives.	HESA HE–BCI: Part A, Section 1
Experience of TTOs (HEPTTOEXP $_{i,t}$)	The difference between the academic year and the year of establishment of the TTO.	HES HE–BCI: Part A, Section 2
Share of research academics (HEPRESAC $_{i,t}$)	The share of academic staff (excluding atypical; both full- and part-time) with research responsibilities among the total academic staff.	HESA Staff Record: Table 6
Quality of research (HEPRESQUAL $_{i}$)	The HEP's GPA, calculated based on the results of the RAE 2008, is determined by multiplying the share of research in each grade by its rating, summing them all, and dividing by 100.	RAE 2008's official web-site
Number of publications (HEPPUBL $_{i,t}$)	The number of publications from the HEP, including articles, reviews, books, book chapters, and conference proceedings.	SciVal

Note: Most of these definitions were adapted from HESA (see https://www.hesa.ac.uk/support/definitions/hebci) and SciVal (see https://service.elsevier.com/app/answers/detail/a_id/13936/supporthub/scival).

Table A.2. List of subject areas by their patentability

HESA code (sorted ↓)	**Subject area**
Patentable subject areas	
101	Clinical medicine
102	Clinical dentistry
103	Nursing and allied health professions
104	Psychology and behavioral sciences
105	Health and community studies
106	Anatomy and physiology
107	Pharmacy and pharmacology
108	Sports science and leisure studies
109	Veterinary science
110	Agriculture, forestry, and food science
111	Earth, marine, and environmental sciences
112	Biosciences
113	Chemistry
114	Physics
115	General engineering
116	Chemical engineering
117	Mineral, metallurgy, and materials engineering
118	Civil engineering
119	Electrical, electronic, and computer engineering
120	Mechanical, aero, and production engineering
121	IT, systems sciences, and computer software engineering
Non-patentable subject areas	
122	Mathematics
123	Architecture, built environment, and planning
124	Geography and environmental studies
125	Area studies
126	Archaeology
127	Anthropology and development studies
128	Politics and international studies
129	Economics and econometrics
130	Law
131	Social work and social policy
132	Sociology
133	Business and management studies
134	Catering and hospitality management
135	Education
136	Continuing education
137	Modern languages
138	English language and literature
139	History
140	Classics
141	Philosophy
142	Theology and religious studies
143	Art and design
144	Music, dance, drama, and performing arts
145	Media studies

Table A.3. Marginal effects

a) Intensity of collaborative research

Scientific impact	The prominence of scientific outlets	Margin	Std.Err.	z	P>z	[95% Conf. Interval]	
0.0	Lower	0.013	0.003	4.560	0.000	0.008	0.019
0.0	Higher	0.030	0.008	3.690	0.000	0.014	0.046
0.5	Lower	0.016	0.003	6.310	0.000	0.011	0.021
0.5	Higher	0.027	0.005	5.080	0.000	0.017	0.038
1.0	Lower	0.019	0.002	9.190	0.000	0.015	0.024
1.0	Higher	0.025	0.003	7.540	0.000	0.018	0.031
1.5	Lower	0.023	0.002	11.010	0.000	0.019	0.028
1.5	Higher	0.023	0.002	10.070	0.000	0.018	0.027
2.0	Lower	0.028	0.003	8.340	0.000	0.022	0.035
2.0	Higher	0.021	0.003	8.010	0.000	0.016	0.026
2.5	Lower	0.034	0.006	5.750	0.000	0.023	0.046
2.5	Higher	0.019	0.003	5.360	0.000	0.012	0.026
3.0	Lower	0.041	0.010	4.240	0.000	0.022	0.060
3.0	Higher	0.017	0.004	3.850	0.000	0.008	0.026

Note: The marginal effects are based on *Model 8*. A lower prominence of scientific outlets is set at the first quartile level, while a higher prominence is set at the third quartile level.

b) Intensity of income from contract research

Scientific impact	The prominence of scientific outlets	Margin	Std.Err.	z	P>z	[95% Conf. Interval]	
0.0	Lower	0.210	0.064	3.290	0.001	0.085	0.335
0.0	Higher	0.584	0.235	2.480	0.013	0.123	1.045
0.5	Lower	0.242	0.053	4.570	0.000	0.138	0.346
0.5	Higher	0.490	0.154	3.180	0.001	0.187	0.792
1.0	Lower	0.279	0.048	5.840	0.000	0.186	0.373
1.0	Higher	0.411	0.098	4.200	0.000	0.219	0.603
1.5	Lower	0.322	0.062	5.230	0.000	0.201	0.443
1.5	Higher	0.345	0.064	5.370	0.000	0.219	0.471
2.0	Lower	0.371	0.098	3.790	0.000	0.179	0.563
2.0	Higher	0.289	0.053	5.480	0.000	0.186	0.393
2.5	Lower	0.428	0.154	2.790	0.005	0.127	0.729
2.5	Higher	0.243	0.056	4.360	0.000	0.134	0.352
3.0	Lower	0.494	0.228	2.160	0.031	0.046	0.941
3.0	Higher	0.204	0.062	3.290	0.001	0.082	0.325

Note: The marginal effects are based on *Model 16*. A lower prominence of scientific outlets is set at the first quartile level, while a higher prominence is set at the third quartile level.

c) Intensity of income from consultancy activities

Scientific impact	The prominence of scientific outlets	Margin	Std.Err.	z	P>z	[95% Conf. Interval]	
0.0	Lower	0.262	0.061	4.310	0.000	0.143	0.381
0.0	Higher	0.441	0.141	3.130	0.002	0.165	0.718
0.5	Lower	0.279	0.046	6.020	0.000	0.188	0.370
0.5	Higher	0.366	0.089	4.130	0.000	0.192	0.540
1.0	Lower	0.298	0.038	7.890	0.000	0.224	0.373
1.0	Higher	0.303	0.054	5.570	0.000	0.197	0.410
1.5	Lower	0.319	0.044	7.210	0.000	0.232	0.405
1.5	Higher	0.251	0.038	6.610	0.000	0.177	0.326
2.0	Lower	0.340	0.066	5.190	0.000	0.212	0.469
2.0	Higher	0.208	0.036	5.720	0.000	0.137	0.280
2.5	Lower	0.364	0.096	3.790	0.000	0.175	0.552
2.5	Higher	0.173	0.041	4.250	0.000	0.093	0.252
3.0	Lower	0.388	0.133	2.920	0.003	0.128	0.649
3.0	Higher	0.143	0.045	3.210	0.001	0.056	0.231

Note: The marginal effects are based on *Model 24*. A lower prominence of scientific outlets is set at the first quartile level, while a higher prominence is set at the third quartile level.

Table A.4. Comparison of various estimation methods

Explanatory variables	Dependent variable = ACADCOLRES $_{i,t}$			Dependent variable = ACADCONTRES $_{i,t}$			Dependent variable = ACADCONSULT $_{i,t}$		
	OLS (baseline)	*Poisson*	*Tobit*	*OLS (baseline)*	*Poisson*	*Tobit*	*OLS (baseline)*	*Poisson*	*Tobit*
IMPSCI $_{i,t-1}$	**1.165*****	**0.428****	**0.011***	**1.171****	**0.925*****	**1.464****	**0.838****	**0.875****	**1.621*****
	(0.354)	*(0.172)*	*(0.591)*	*(0.523)*	*(0.358)*	*(0.676)*	*(0.369)*	*(0.356)*	*(0.606)*
IMPECON $_{i,t-1}$	**0.0028***	0.0006	-0.00001	0.0005	**-0.0017****	**-0.0034***	-0.0017	**-0.0058****	**-0.0161***
	(0.0015)	*(0.0006)*	*(0.00002)*	*(0.0016)*	*(0.0008)*	*(0.0018)*	*(0.0019)*	*(0.0023)*	*(0.0088)*
IMPSOC $_{i,t-1}$	-0.048	-0.005	-0.002	-0.034	0.011	-0.036	-0.013	0.064	-0.039
	(0.144)	*(0.091)*	*(0.002)*	*(0.185)*	*(0.135)*	*(0.085)*	*(0.167)*	*(0.092)*	*(0.158)*
PROMJOURN $_{i,t-1}$	**0.048*****	**0.018****	0.0004	**0.060*****	**0.064****	**0.088***	**0.031****	**0.064*****	**0.106****
	(0.017)	*(0.007)*	*(0.0003)*	*(0.023)*	*(0.031)*	*(0.052)*	*(0.014)*	*(0.022)*	*(0.049)*
IMPSCI $_{i,t-1}$ × PROMJOURN $_{i,t-1}$	**-0.033*****	**-0.011****	**-0.0003***	**-0.037****	**-0.032****	**-0.057***	**-0.030*****	**-0.031****	**-0.070*****
	(0.011)	*(0.004)*	*(0.0002)*	*(0.015)*	*(0.014)*	*(0.030)*	*(0.011)*	*(0.013)*	*(0.027)*
PROMMEDIA $_{i,t-1}$	0.617	0.055	0.007	0.464	-0.029	-0.088	0.147	0.423	-0.738
	(0.554)	*(0.374)*	*(0.011)*	*(0.507)*	*(0.508)*	*(0.396)*	*(0.508)*	*(0.335)*	*(0.653)*
IMPSOC $_{i,t-1}$ × PROMMEDIA $_{i,t-1}$	0.017	-0.034	0.001	0.211	-0.095	-0.052	-0.048	-0.162	-0.336
	(0.189)	*(0.115)*	*(0.003)*	*(0.238)*	*(0.231)*	*(0.155)*	*(0.254)*	*(0.123)*	*(0.347)*
HEP controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HEP fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-sq: between/overall	0.85/0.61	-	-	0.68/0.57	-	-	0.61/0.49	-	-
Log (pseudo)likelihood	-	-144.467	2,650.536	-	-1,247.038	-1,929.751	-	-1,116.064	-2,506.173
Number of clusters	133	133	133	133	133	133	133	133	133
Number of observations	1,064	1,064	1,064	1,064	1,064	1,064	1,064	1,064	1,064

* 10% significance; ** 5% significance; *** 1% significance. Standard errors (in parentheses) are clustered at the HEP level; in the tobit models, standard errors are bootstrapped with 50 iterations. The constant is included in all models but is not reported.

Note: The dependent variables are log-transformed only in the baseline (*OLS*) specification. When calculating the natural logarithm of variables with a value of zero, we added 0.0001. HEP fixed effects are based on the following: (i) for ACADCOLRES, the HEP's five-year (2006–2010) pre-sample average of the dependent variable; (ii) for ACADCONTRES and ACADCONSULT, the HEP's five-year (2006–2010) pre-sample average ratio of the total income from research grants and contracts to the total number of academic staff (see Blundell *et al*., 1999). "*Poisson*" refers to a Poisson model. "*Tobit*" refers to a tobit model.

Table A.5. Alternative specification for the scientific impact variable: All publications versus articles and reviews only

Explanatory variables	Dependent variable = ACADCOLRES $_{i,t}$		Dependent variable = ACADCONTRES $_{i,t}$		Dependent variable = ACADCONSULT $_{i,t}$	
	All publications (baseline)	*Articles and reviews only*	*All publications (baseline)*	*Articles and reviews only*	*All publications (baseline)*	*Articles and reviews only*
IMPSCI $_{i,t-1}$	**1.165****** *(0.354)*	**0.965****** *(0.234)*	**1.171***** *(0.523)*	**0.819**** *(0.451)*	**0.838***** *(0.369)*	0.282 *(0.227)*
IMPECON $_{i,t-1}$	**0.0028**** *(0.0015)*	0.0021 *(0.0014)*	0.0005 *(0.0016)*	0.0005 *(0.0012)*	-0.0017 *(0.0019)*	-0.0011 *(0.0013)*
IMPSOC $_{i,t-1}$	-0.048 *(0.144)*	-0.026 *(0.155)*	-0.034 *(0.185)*	-0.054 *(0.196)*	-0.013 *(0.167)*	-0.015 *(0.172)*
PROMJOURN $_{i,t-1}$	**0.048****** *(0.017)*	**0.054****** *(0.015)*	**0.060****** *(0.023)*	**0.056****** *(0.019)*	**0.031***** *(0.014)*	0.014 *(0.014)*
IMPSCI $_{i,t-1}$ × PROMJOURN $_{i,t-1}$	**-0.033****** *(0.011)*	**-0.028****** *(0.007)*	**-0.037***** *(0.015)*	**-0.028***** *(0.012)*	**-0.030****** *(0.011)*	**-0.012**** *(0.007)*
PROMMEDIA $_{i,t-1}$	0.617 *(0.554)*	0.306 *(0.654)*	0.464 *(0.507)*	0.517 *(0.496)*	0.147 *(0.508)*	0.187 *(0.502)*
IMPSOC $_{i,t-1}$ × PROMMEDIA $_{i,t-1}$	0.017 *(0.189)*	0.095 *(0.203)*	0.211 *(0.238)*	0.236 *(0.257)*	-0.048 *(0.254)*	-0.057 *(0.254)*
HEP controls	Yes	Yes	Yes	Yes	Yes	Yes
HEP fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-sq: between/overall	0.85/0.61	0.86/0.56	0.68/0.57	0.68/0.57	0.61/0.49	0.60/0.48
Number of clusters	133	133	133	133	133	133
Number of observations	1,064	1,064	1,064	1,064	1,064	1,064

* 10% significance; ** 5% significance; *** 1% significance. Standard errors (in parentheses) are clustered at the HEP level. The constant is included in all models but is not reported.

Note: The dependent variables are log-transformed. When calculating the natural logarithm of variables with a value of zero, we added 0.0001. HEP fixed effects are based on the following: (i) for ACADCOLRES, the HEP's five-year (2006–2010) pre-sample average of the dependent variable; (ii) for ACADCONTRES and ACADCONSULT, the HEP's five-year (2006–2010) pre-sample average ratio of the total income from research grants and contracts to the total number of academic staff (see Blundell *et al.*, 1999). "*Articles and reviews only*" refers to models in which the intensity of collaborative research, the scientific impact, and the economic impact are calculated solely based on articles and reviews.

Table A.6. Alternative specification for the scientific impact variable: Publication citations versus publication views

Explanatory variables	Dependent variable = ACADCOLRES $_{i,t}$		Dependent variable = ACADCONTRES $_{i,t}$		Dependent variable = ACADCONSULT $_{i,t}$	
	Publication citations (baseline)	*Publication views*	*Publication citations (baseline)*	*Publication views*	*Publication citations (baseline)*	*Publication views*
IMPSCI $_{i,t-1}$	**1.165*****	0.322	**1.171****	-0.015	**0.838****	0.071
	(0.354)	*(0.231)*	*(0.523)*	*(0.176)*	*(0.369)*	*(0.087)*
IMPECON $_{i,t-1}$	**0.0028***	**0.0029****	0.0005	0.0004	-0.0017	-0.0019
	(0.0015)	*(0.0013)*	*(0.0016)*	*(0.0018)*	*(0.0019)*	*(0.0018)*
IMPSOC $_{i,t-1}$	-0.048	-0.030	-0.034	-0.048	-0.013	-0.024
	(0.144)	*(0.151)*	*(0.185)*	*(0.198)*	*(0.167)*	*(0.175)*
PROMJOURN $_{i,t-1}$	**0.048*****	0.019	**0.060*****	0.020	**0.031****	0.005
	(0.017)	*(0.015)*	*(0.023)*	*(0.016)*	*(0.014)*	*(0.010)*
IMPSCI $_{i,t-1}$ × PROMJOURN $_{i,t-1}$	**-0.033*****	-0.007	**-0.037****	-0.001	**-0.030*****	-0.006
	(0.011)	*(0.007)*	*(0.015)*	*(0.007)*	*(0.011)*	*(0.004)*
PROMMEDIA $_{i,t-1}$	0.617	0.623	0.464	0.406	0.147	0.114
	(0.554)	*(0.571)*	*(0.507)*	*(0.521)*	*(0.508)*	*(0.484)*
IMPSOC $_{i,t-1}$ × PROMMEDIA $_{i,t-1}$	0.017	-0.020	0.211	0.202	-0.048	-0.051
	(0.189)	*(0.195)*	*(0.238)*	*(0.257)*	*(0.254)*	*(0.258)*
HEP controls	Yes	Yes	Yes	Yes	Yes	Yes
HEP fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-sq: between/overall	0.85/0.61	0.86/0.60	0.68/0.57	0.68/0.56	0.61/0.49	0.59/0.47
Number of clusters	133	133	133	133	133	133
Number of observations	1,064	1,064	1,064	1,064	1,064	1,064

* 10% significance; ** 5% significance; *** 1% significance. Standard errors (in parentheses) are clustered at the HEP level. The constant is included in all models but is not reported.

Note: The dependent variables are log-transformed. When calculating the natural logarithm of variables with a value of zero, we added 0.0001. HEP fixed effects are based on the following: (i) for ACADCOLRES, the HEP's five-year (2006–2010) pre-sample average of the dependent variable; (ii) for ACADCONTRES and ACADCONSULT, the HEP's five-year (2006–2010) pre-sample average ratio of the total income from research grants and contracts to the total number of academic staff (see Blundell *et al.*, 1999). "*Publication views*" refers to models in which the scientific impact is measured as the ratio of the total number of views received by publications of the HEP to the expected world average for the subject field, publication type, and publication year.

Table A.7. Alternative specification for the social impact variable: Mentions in print media versus mentions in on-line media

Explanatory variables	Dependent variable = ACADCOLRES $_{i,t}$		Dependent variable = ACADCONTRES $_{i,t}$		Dependent variable = ACADCONSULT $_{i,t}$	
	Print media (baseline)	*On-line media*	*Print media (baseline)*	*On-line media*	*Print media (baseline)*	*On-line media*
IMPSCI $_{i,t-1}$	**1.165*****	**0.960****	**1.171****	0.950	**0.838****	**0.685****
	(0.354)	*(0.419)*	*(0.523)*	*(0.594)*	*(0.369)*	*(0.287)*
IMPECON $_{i,t-1}$	**0.0028***	0.0015	0.0005	0.0006	-0.0017	-0.0013
	(0.0015)	*(0.0039)*	*(0.0016)*	*(0.0035)*	*(0.0019)*	*(0.0038)*
IMPSOC $_{i,t-1}$	-0.048	-0.065	-0.034	0.047	-0.013	-0.385
	(0.144)	*(0.279)*	*(0.185)*	*(0.550)*	*(0.167)*	*(0.594)*
PROMJOURN $_{i,t-1}$	**0.048*****	**0.034****	**0.060*****	**0.051****	**0.031****	0.025
	(0.017)	*(0.017)*	*(0.023)*	*(0.025)*	*(0.014)*	*(0.018)*
IMPSCI $_{i,t-1}$ × PROMJOURN $_{i,t-1}$	**-0.033*****	**-0.029****	**-0.037****	**-0.033***	**-0.030*****	**-0.020***
	(0.011)	*(0.013)*	*(0.015)*	*(0.018)*	*(0.011)*	*(0.011)*
PROMMEDIA $_{i,t-1}$	0.617	0.030	0.464	0.159	0.147	0.138
	(0.554)	*(0.619)*	*(0.507)*	*(1.012)*	*(0.508)*	*(1.032)*
IMPSOC $_{i,t-1}$ × PROMMEDIA $_{i,t-1}$	0.017	0.239	0.211	-0.052	-0.048	0.212
	(0.189)	*(0.481)*	*(0.238)*	*(0.948)*	*(0.254)*	*(0.998)*
HEP controls	Yes	Yes	Yes	Yes	Yes	Yes
HEP fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-sq: between/overall	0.85/0.61	0.79/0.60	0.68/0.57	0.63/0.54	0.61/0.49	0.60/0.51
Number of clusters	133	133	133	133	133	133
Number of observations	1,064	665	1,064	665	1,064	665

* 10% significance; ** 5% significance; *** 1% significance. Standard errors (in parentheses) are clustered at the HEP level. The constant is included in all models but is not reported.

Note: The dependent variables are log-transformed. When calculating the natural logarithm of variables with a value of zero, we added 0.0001. HEP fixed effects are based on the following: (i) for ACADCOLRES, the HEP's five-year (2006–2010) pre-sample average of the dependent variable; (ii) for ACADCONTRES and ACADCONSULT, the HEP's five-year (2006–2010) pre-sample average ratio of the total income from research grants and contracts to the total number of academic staff (see Blundell *et al.*, 1999). "*On-line media*" refers to models in which social impact is measured as the ratio of the total number of mentions in the on-line media received by publications of the HEP to the expected world average for the subject field, publication type, and publication year. The observation period for this measure is between 2014 and 2019.

Table A.8. Subsample analysis: Russell Group universities versus all other universities

Explanatory variables	Dependent variable = ACADCOLRES $_{i,t}$			Dependent variable = ACADCONTRES $_{i,t}$			Dependent variable = ACADCONSULT $_{i,t}$		
	All (baseline)	*Russell Group*	*Other universities*	*All (baseline)*	*Russell Group*	*Other universities*	*All (baseline)*	*Russell Group*	*Other universities*
IMPSCI $_{i,t-1}$	**1.165*****	**-0.547***	**1.173*****	**1.171****	-0.072	**1.283****	**0.838****	2.640	**0.859****
	(0.354)	*(0.324)*	*(0.384)*	*(0.523)*	*(0.905)*	*(0.554)*	*(0.369)*	*(2.436)*	*(0.386)*
IMPECON $_{i,t-1}$	**0.0028***	**0.0007***	**0.0039****	0.0005	0.0008	0.0019	-0.0017	-0.0048	-0.0010
	(0.0015)	*(0.0004)*	*(0.0018)*	*(0.0016)*	*(0.0014)*	*(0.0019)*	*(0.0019)*	*(0.0035)*	*(0.0024)*
IMPSOC $_{i,t-1}$	-0.048	0.117	-0.048	-0.034	-0.363	-0.038	-0.013	-0.612	-0.012
	(0.144)	*(0.122)*	*(0.145)*	*(0.185)*	*(0.332)*	*(0.187)*	*(0.167)*	*(0.831)*	*(0.172)*
PROMJOURN $_{i,t-1}$	**0.048*****	**-0.033***	**0.049*****	**0.060*****	0.030	**0.065*****	**0.031****	0.081	**0.032****
	(0.017)	*(0.019)*	*(0.018)*	*(0.023)*	*(0.040)*	*(0.024)*	*(0.014)*	*(0.113)*	*(0.014)*
IMPSCI $_{i,t-1}$ × PROMJOURN $_{i,t-1}$	**-0.033*****	**0.013***	**-0.034*****	**-0.037****	0.003	**-0.043*****	**-0.030*****	-0.061	**-0.031*****
	(0.011)	*(0.008)*	*(0.013)*	*(0.015)*	*(0.021)*	*(0.016)*	*(0.011)*	*(0.055)*	*(0.012)*
PROMMEDIA $_{i,t-1}$	0.617	0.302	0.646	0.464	0.664	0.459	0.147	-1.487	0.189
	(0.554)	*(0.385)*	*(0.558)*	*(0.507)*	*(0.830)*	*(0.523)*	*(0.508)*	*(1.966)*	*(0.520)*
IMPSOC $_{i,t-1}$ × PROMMEDIA $_{i,t-1}$	0.017	-0.164	0.005	0.211	0.354	0.238	-0.048	0.470	-0.059
	(0.189)	*(0.138)*	*(0.193)*	*(0.238)*	*(0.405)*	*(0.241)*	*(0.254)*	*(0.995)*	*(0.264)*
HEP controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HEP fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-sq: between/overall	0.85/0.61	0.99/0.90	0.85/0.59	0.68/0.57	0.92/0.83	0.65/0.52	0.61/0.49	0.78/0.53	0.62/0.49
Number of clusters	133	24	109	133	24	109	133	24	109
Number of observations	1,064	192	872	1,064	192	872	1,064	192	872

* 10% significance; ** 5% significance; *** 1% significance. Standard errors (in parentheses) are clustered at the HEP level. The constant is included in all models but is not reported.

Note: The dependent variables are log-transformed. When calculating the natural logarithm of variables with a value of zero, we added 0.0001. HEP fixed effects are based on the following: (i) for ACADCOLRES, the HEP's five-year (2006–2010) pre-sample average of the dependent variable; (ii) for ACADCONTRES and ACADCONSULT, the HEP's five-year (2006–2010) pre-sample average ratio of the total income from research grants and contracts to the total number of academic staff (see Blundell *et al*., 1999). "*Russell Group*" refers to a group of 24 UK research-intensive universities (visit www.russellgroup.ac.uk for more information).