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Star scientists versus interdisciplinary scientists: exploring the distinct patterns of engagement in university-industry interactions

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Abstract

This paper investigates two facets of the science-base industry linkages. First, we examine whether interdisciplinary scientists exhibit a distinct propensity to interact with industry as compared to star scientists. Second, we investigate whether the effects of scientific impact and interdisciplinarity on the propensity of scientists to interact with industry are contingent on the particular mode of university-industry interaction. We distinguish between three modes of university-industry interaction: entrepreneurial, co-production and response modes. We find that the effects of scientific impact on university-industry interactions are non-linear and largely dependent on the interaction mode. In contrast, we find that interdisciplinary research is positively associated with all modes of university-industry interaction. Additionally, we find that the effects of scientific impact and interdisciplinary research are moderated by two individual attributes:

perceived social impact of research and previous experience of scientists in industry interactions. Our hypotheses are tested on a sample of 1.213 scientists from the Spanish Council for Scientific Research (CSIC), the largest public research organization in Spain, covering a wide range of scientific fields, including physics, engineering, biomedicine, social sciences and humanities. We combine primary data from a large scale survey, bibliometric data on the publications of scientists, and administrative data on the past interactions with industry in which scientists have been involved.

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1. INTRODUCTION

Universities and public research organizations (PRO), as key sources of scientific knowledge production, are expected to actively contribute and foster technological progress and innovation (Cohen et al., 2002; Jaffe, 1989). The connection between the scientific production and industrial innovation is, however, far from a mechanical translation between scientific discovery and technological application. On the one hand, due to the distinct logics governing scientific production and innovation (Gittelman & Kogut, 2003; Sauerman & Stephan, 2012), it is a matter of discussion whether scientific impact may systematically represent an antecedent of technological developments, or whether instead one should search for antecedents in specific profiles of academic research, such as interdisciplinary approaches. On the other hand, the connections between the science base and industry are articulated through variegated types of inter-organisational agreements, which are often led by industrial partners or organized as collaborative partnerships (Perkmann & Walsh, 2007; D'Este and Patel, 2007), contrasting with a supply-driven approach from scientific research to industrial application.

This paper aims to contribute to these two facets of the science base – industry linkages, by highlighting the importance of (i) interdisciplinary research profiles of scientists and (ii) the specificities associated to the multiple modes of university-industry interaction. First, our research investigates whether interdisciplinary scientists - as compared to star scientists - are particularly prone to engage in science base - industry interactions. While scientific impact appears to be a positive predictor of scientists' engagement in university-industry activities, since successful scientists are expected to produce results with higher value for industrial actors and benefit from greater visibility outside academia (Zucker et al., 1998), it is also recognized that engaging with industry might require a set of specific skills and capabilities that are substantially different from those required to succeed in academia (Bercovitz and Feldman, 2008; Perkmann et al., 2011).

Second, our research contends that the predictive power of scientific excellence and interdisciplinarity in the propensity of scientists to engage in university-industry interactions differs according to the specific mode of university-industry interaction. In this study, the multiplex nature of university-industry interactions is brought to the foreground differentiating between three modes of formal university-industry interactions: entrepreneurial mode, co-production mode and response mode. We propose that the effects of scientific impact and interdisciplinarity on university-industry interactions are non-linear and largely dependent on the interaction mode. Additionally, we suggest that the potential effects of scientific impact and interdisciplinarity should be studied in conjunction with two relevant individual attributes: the perceived social impact of research and the previous experience of scientists in interacting with industry.

Our hypotheses are tested on a sample of 1.213 scientists affiliated to the Spanish Council for Scientific Research (CSIC), the largest public research organization in Spain covering all scientific fields, from physics and engineering, to biomedicine and social sciences and humanities. We combine primary data from a large scale survey, bibliometric data on scientists' publications and administrative data about demographic characteristics of scientists and their past involvement in interactions with industry.

The paper is structured as follows. Section 2 provides the theoretical background to the paper and Section 3 discusses and puts forward a set of hypotheses. Section 4 presents the dataset and describes the sample, the variables and the method used for the empirical analysis. Section 5 presents the results of the econometric analysis, and Section 6 synthesizes the main findings and discusses the implications of the study.

2. CONCEPTUAL FRAMEWORK

Modes of university-industry (U-I) interactions[1]

The subject of how university research contributes to innovation and how business' technological needs stimulate academic research, has motivated a long-standing interest in the analysis of university-industry interactions. Contributions to the analysis of university-industry

[1] We refer throughout the text to 'university-industry' interactions as a broad category to reflect all types of linkages between the science base and industry, thus including interactions between industry and both universities and public research organizations (PROs).

interactions have come from several fields of research, from the economics of innovation and management studies (Kotha et al., 2013; Zucker et al., 2002) to science policy research and the sociology of science (Lam, 2011; Tartari et al., 2014). This has been matched by public policies oriented to enhance the collaboration between academic scientists and potential users of research, in order to foster research that addresses societal problems.

It is well-accepted, however, that the interactions between the science base and industry represent a very broad domain, embracing multiple types of linkages between academic scientists and business practitioners (Abreu and Grinevich, 2013; Cohen et al., 2002; D'Este and Patel, 2007). Even though some frameworks have been suggested to capture the different dimensions of these interactions (Bonaccorsi et al., 2012; Howells et al., 1998; Poyago-Theotoky et al., 2002), much of the empirical research remains highly fragmented in its understanding of the diverse forms of university-industry links. This represents an important weakness in this literature, since it undermines a systematic and conceptually-based analysis of the distinct (or similar) mechanisms underlying the enactment and impact of the multiple types of university-industry interactions.

In this section, we propose an analytical framework that provides a rationale to categorise the diverse nature of university-industry interactions. While the framework provided refers mainly to formal interactions - that is, those linkages that can be traced through a documented contractual agreement - it is susceptible to apply to informal types of interactions. Building on Perkmann and Walsh (2007), we propose a framework in which university-industry interactions can be logically organized along two critical dimensions: a) the type of *contractual agreement*; and b) the form of *finalization*.

By type of *contractual agreement* we refer to the extent to which university-industry interactions are governed by market mechanisms, where buyers and sellers meet for a one-off exchange of highly standardized technologies and know-how, or instead they are governed by frequent and personal-based relationships involving the exchange of tacit knowledge and idiosyncratic assets (Williamson, 1985). Links that involve a high degree of personal involvement are exemplified by situations where academic and industrial researchers work together over sustained periods of time in purse of a shared goal. This epitomises what we call: *relational* arrangements, which are largely based on the development of truthful relations between actors. By contrast, links with low degree of personal involvement can be represented by situations that do not require a direct and sustained relationship between individuals in academic and business contexts in order to materialize an effective interaction, as in the case of the licensing of university-generated IP. This exemplifies what we call: *transactional* arrangements, which are largely based on the establishment of a market-based agreement for the transfer of knowledge and technology.

Finalization refers to the degree to which university-industry interactions are driven by the expectation to generate results for well-defined and clearly specified targets versus interactions that are driven by more open-ended goals and ill-defined problem solving. The former type of interaction is exemplified by situations where academic scientists respond to specific needs of industrialists, for instance, by carrying out an assignment against payment in the case of consulting activities. This type of interactions may involve different degrees of original research on the behalf of the academic partner, embracing cases where no original research is requested. It can also be illustrated by situations in which the leading role is taken by the academic scientist, where scientists develop an invention that is susceptible of knowledge codification and standardized transaction in markets for technology. We call these types of interaction as: *targeted* arrangements. The contrasting type of interactions according to finalization is exemplified by situations where both academic and industry researchers pursue exploratory outcomes from research (as in the case of long-term R&D collaborative research projects) or when they address ill-defined problem-solving activities (as in the case in which scientists decide to set up a company or work with industrialists to reach a convincing proof of concept for their inventions). We call these types of interactions as: *open-ended* arrangements.

The two dimensions discussed above provide a rationale to map and position the multiple types of formal university-industry interactions: see Figure 1. Quadrants 1 and 2 (in Figure 1) represent two alternative expressions of the “entrepreneurial mode” of university-industry interactions. The entrepreneurial mode is characterised by academic researchers who take a leading role in the development of discoveries and technologies that emerge from their own university research, and take actions towards the commercial exploitation of these inventions either through the licensing of intellectual property rights (such as patents), Quadrant 2, or through the establishment of a company (i.e. spin offs), Quadrant 1. In the case of Quadrant 2, we have an instantiation of *transfer of technology* into industrial settings, through the commercialisation of a highly codified knowledge with market potential. Thus, the intersection between a transactional and targeted university-industry interaction, reflects the paradigmatic case of technology transfer, as illustrated by the licensing of university-generated IP.

In the case of Quadrant 1, academic scientists do not generally have a ready-to-sell technology, and very often further development is required to reach a credible proof-of-concept or a final product suitable for commercialisation, which leads to the formation of a spin-off company by the academic inventor (often in partnership with industrial practitioners). While deeply ingrained in a transactional, market-based approach, this mode reflects a situation where high degrees of uncertainty and substantial challenges regarding technological-related problem solving, are both present. For this reason we categorise this entrepreneurial mode of spin-off creation at the intersection of transactional and open-ended university-industry interactions. In short, these two instantiations of the “entrepreneurial mode” share the fundamental characteristic that both combine the capacity of the academic researchers to realise the application and commercial potential of their research, and the disposition to resort to market-based transaction mechanisms to articulate the development and commercialisation of an invention.

Quadrant 3 represents the intersection between relational and targeted arrangements. Similar to the “technology transfer” mode of Quadrant 2, the knowledge object of the interaction is in a highly codified form or highly susceptible of codification. However, the critical differences with respect to the “technology transfer” mode refer to: (i) it is a relational form of interaction (as opposed to a transactional one) since the personal and face-to-face relationship between academic and industrialist is fundamental to reach an effective arrangement; (ii) it is characterised as industry-pull (as opposed to university-push) since it is the industrial partner who sets the terms of the arrangement regarding goals and objectives; and (iii) while these arrangements can be featured as a transfer mode, it is not characterised by technology transfer but by the transfer of knowledge or expertise: academic researchers provide a service to industrialists, rather than a technology. Under this quadrant we can clearly position both consulting activities and contract research. While contract research often requires some degree of original research being conducted on the academic side, the boundaries between consulting and contract research are fuzzy, as both are characterised by activities commissioned by industrial clients. Accordingly, we label this as a "response mode" of university-industry interactions.

Quadrant 4 represents the intersection between relational and open-ended arrangements. This situation is, to some extent, similar to the "response mode" in the sense that both fundamentally rely on a relational, personal-based contracting approach. It is even more so in this case, where academic and industrialists address highly open-ended research goals. In this context, the critical challenge is to make effective the pooling of tacit knowledge and highly specific expertise of academic and industrial scientists to address ill-defined problem solving activities that will require face-to-face and frequent interaction over extended periods of time. As opposed to the previous cases, this is neither a mode characterised by an academic scientists push or an industrial demand pull approach, but instead, this is characterised by a joint effort towards co-production of knowledge, the success of which is largely dependent on enacting tacit knowledge and building trust between the parties involved. Thus, this quadrant can be exemplified by long-term R&D collaborative projects and R&D partnerships, more generally. We label this as a "co-production mode" of university-industry interactions. Figure 1 illustrates thee two dimensions and the four modes discussed above.

FIGURE 1:
Modes of Formal University – Industry Interactions

FINALIZATION	(1) / (2): **Transactional** (market-based)	(4) / (3): **Relational** (trust-based)
Open-ended	(1) ***Entrepreneurial Mode I: Firm creation*** (academic entrepreneurship) *Spin-off formation*	(4) ***Co-production Mode*** *(research partnerships)*
Targeted	(2) ***Entrepreneurial Mode II: Technology transfer*** (academic entrepreneurship) *Licensing of IP*	(3) ***Response Mode*** *(research services)*

CONTRACTUAL AGREEMENT

While we are deliberately not addressing informal interactions in this study, it is worth noting that informal interactions would largely correspond to arrangements in the boundaries between the "response mode" and the "co-production" categories, insofar as informal interactions are critically dependent on a relational component, they can either be initiated by academics or industrialists, and have varying degrees of goal definition.

3. HYPOTHESES

Bridging science and innovation: star scientists vs. interdisciplinary scientists

Scientists who manage to reconcile the logics of scientific discovery and technological development, often called 'bridging scientists', have a critical importance in the generation of valuable inventions (Gittelman and Kogut, 2003). This is so because these scientists are capable to realise the potential applicability of the results of leading-edge academic research and, at the same time, are highly receptive to undertake exploratory research inspired by the insights from challenges that industrialists face in their innovation processes. It does not come as a surprise, then, that academic researchers who bridge scientific and technological domains are in great demand. More so since bridging scientists are not a common species and can be often difficult to find in academic research environments.

One of the reasons that has been put forward to explain why ‘bridging scientists’ are a rare phenomenon is based on the argument that the prevailing norms and incentives that rule the academic environment, largely based on (i) *publication priority* and *scientific impact* and (ii) *disciplinary-based* recognition, make the transit between academic research and engagement in university-industry interactions far from straightforward. As this argument goes, “the logic of scientific discovery does not adhere to the same logic that governs the development of new technologies” (Gittleman & Kogut, 2003: 367), and reconciling both logics entails some fundamental changes in the scientist role identity towards a more hybrid personality (Jain et al., 2009).

We take hold on this issue by investigating some contrasting views about the antecedents of bridging scientists. On the one hand, it is a matter of contention whether scientific priority and recognition do undermine or rather encourage the engagement in university-industry interactions. This is so because, despite of the arguments highlighted above about the conflicting logics of science and innovation, a great deal of evidence suggests that it is precisely prolific scientists who are more engaged in university-industry interactions (Perkmann et al., 2013). On the other hand, it is also a matter of contention to determine whether mono-disciplinary approaches, as opposed to multi and interdisciplinary ones, undermine or encourage engagement in university-industry interactions. In here the existing evidence is also pretty mixed, pointing out to further inquiry on this matter (Molas-Gallart et al., 2014). We further elaborate on these two contentious themes, next.

Stardom and star scientists

The logic of stardom suggests that star scientists are particularly well-positioned to fulfil the role of bridging scientists. This is so for the following two reasons. First, star scientists are particularly susceptible to contribute to breakthrough discoveries and therefore more likely to develop inventions with potential commercial value. This pattern is paradigmatically exemplified by the case of university spin-offs in biotechnology. As Zucker et al. (1998) have pointed out, the participation of university star scientists has been fundamental in the emergence and commercial success of biotechnology companies in the US. Examining a more diverse sample of academic scientists, Lowe and Gonzalez-Brambila (2007) also find that faculty entrepreneurs are much more likely to be high impact scientists (based on citations to their work) than their graduate school peers or the population of faculty in general. Finally, there is additional empirical evidence showing the existence of a positive correlation between scientific productivity and engagement in university-industry interactions (Bekkers and Bodas Freitas, 2008; Gulbrandsen and Smeby, 2005; Louis et al., 1989). Second, star scientists enjoy the benefits of higher visibility and credibility for their research discoveries, within both academic and non-academic environments, which increases their chances of being singled out by private companies when identifying potential collaborators. This attraction effect is further reinforced by the connection between scientific productivity and success in fund-raising, making prolific scientists even more potentially attractive for non-academic partners (Perkmann et al., 2013). In sum, drawing on these two arguments, the proposition based on the stardom logic would sustain that star scientists are more likely to be involved in university-industry interactions, compared to less prominent scientists.

We contend that this claim requires a number of significant qualifications. First, as we have discussed in the sub-Section 2.1, there are multiple forms in which academic scientists may engage in university-industry interactions. Even though stardom may play a positive role in facilitating academic engagement, this role may differ depending on the mode of university-industry interaction. The ‘entrepreneurial’, ‘co-production’ and ‘response’ modes have fundamental differences between each other, as previously discussed, which are likely to impact on the particular role of stardom in shaping university-industry interactions.

More specifically, the behavioural features of star scientists seem to match the requirements of an ‘entrepreneurial mode’, characterised by a science-push discovery process where academic scientists take the lead in both identifying a commercial opportunity to their breakthrough inventions and search for the most suitable channels to bring the invention into the marketplace – either through licensing of intellectual property rights or through the creation of a company. By contrast, star scientists may be reluctant to engage in interactions characterised as ‘response mode’ (i.e. consulting and contract research), as these interactions may imply time detracted to their research agenda, since such interactions are not generally associated with the undertaking of leading-edge research. This negative association seems to be particularly acute when examining the frequency of engagement in consulting activities, as shown by evidence pointing out that scientists who are most frequently involved in consulting exhibit a weaker scientific performance (Rentocchini et al., 2014). Also, insofar as star scientists are often successful fund-raisers, they may be particularly reluctant to engage in ‘response mode’ interactions as compared to research colleagues who have lower availability of funding sources for research.

Finally, it is unclear whether star scientists are more or less likely to be involved in interactions characterised as ‘co-production mode’. This is so because, while this mode implies a high degree of relational involvement that may detract or divert time and resources for pursuing star scientists’ research agenda, such interactions can potentially be highly complementary to the research profile of star scientists, involving explorative research and bringing together specialised expertise, equipment and resources from non-academic partners, which would be otherwise unavailable for the academic scientists. As a result, we remain eclectic about whether stardom is positively or negatively associated to engagement in co-production modes.

Drawing on this discussion we qualify the stardom logic along the lines of the following proposed hypothesis:

H1: Star scientists' involvement in university-industry interactions is dependent on the mode of interaction. Being a star scientists is likely to have a positive effect on the adoption of an 'entrepreneurial mode', while it is likely to have a negative effect on the adoption of a 'response mode'.

The second qualification refers to the absence of a monotonic relationship. It is important to note that the argument of stardom is inherently associated to the idiosyncratic role of scientific elites: scientists who enjoy a particular high reputation within their respective academic communities. In other words, the star scientist argument may imply that the positive relationship with engagement in interactions with industry may only work for a particular sub-set of academic scientists: i.e. scientists who are at the very top of the reputation ladder. Accordingly, we should expect that the role of prestige on the involvement in university-industry interactions is likely to be non-linear: that is, it is only likely to be effective beyond a certain level, arguably a very high level, of reputation and prestige. Below such levels, which accounts for the large majority of scientists in a particular research community, it is unlikely that scientist would enjoy the benefits of visibility and credibility that are necessary to attract non-academic partners. Building on this argument, we further refine our contention by putting forward the following hypothesis:

H2: Star scientists' involvement in university-industry interactions is likely to be non-linear, showing a J-shape relationship, where the positive effects of stardom on university-industry interactions only materialize for particularly high levels of scientific impact.

The third contention refers to complementary attributes. If true, as many scholars argue, that scientific discovery and technological development represent very distinct logics (Gittelman and Kogut, 2003; Jain et al., 2009), we should expect that stardom, by itself, should not necessarily be positively related to engagement in university-industry interactions, unless scientists possess some complementary attributes. While star scientists may excel at scientific discovery, they may find it difficult to realise the commercial opportunities or applicability of their findings.

In that respect, it is well-accepted that scientists who are motivated by a quest for scientific relevance and use in their research activities and in the results of their research, in addition to share a motivation for fundamental understanding, are more likely to be engaged in interactions with stakeholders (Olmos Peñuela et al., 2014; Stokes, 1997). Following this argument, we put forward the following hypothesis:

H3: The positive role of star scientists in shaping involvement in university-industry interactions will be enhanced by the extent to which academic scientists are inspired by the utility and social impact of their research. We argue that this positive interplay will affect all three modes of interaction: entrepreneurial, co-production and response modes.

Interdisciplinary scientists and cognitive integration

Interdisciplinary research refers to research approaches that combine and integrate separate bodies of knowledge, including different methods, concepts and theories (Wagner et al., 2011). Thus, interdisciplinarity involves a degree of communication and cross-fertilization across academic disciplines (Jacobs and Frickel, 2009). Attempts to promote interdisciplinary approaches have come from numerous sources (Brint, 2005), generally drawing on the claim that interdisciplinary research is associated with the capacity to identify better ways of solving complex problems and generate new research avenues that help rejuvenate science while challenging established beliefs (Barry et al., 2008; Jacobs and Frickel, 2009; Rafols et al., 2012). This rationale draws on the logic that interdisciplinary research enhances cross-fertilization of ideas due to scientists spanning multiple ways of understanding and being exposed to distinct approaches to address particular research problems. Indeed, several studies argue that combining distant knowledge domains in scientific research results in fundamental breakthrough discoveries, often with a potentially high market value (Ahuja and Lampert, 2001; Fleming and Sorenson, 2004; Kotha et al., 2013). In short, this suggests that interdisciplinary research might favour the emergence of scientists who are particularly likely to bridge the fields of science and innovation.

However, the institutionalisation of science in terms of well-bounded disciplines often represents a barrier for the emergence of interdisciplinary approaches. The norms and rules that govern the scientific enterprise in the everyday management of universities, conferences, recruitment, journals and peer-review processes, strongly favour mono-disciplinary approaches

(Barry et al., 2008; Bruce et al., 2004). As a result, it is legitimate to wonder whether, and to what extent, the mono-disciplinary approach that dominates the organisation of scientific research, acts as a barrier to scientists' participation in university-industry interactions.

The interdisciplinary logic would sustain that scientists are particularly well-positioned to act as bridging scientists for the following two reasons. First, due to their boundary-spanning positions, they are likely to supply creative ideas to sort out currently unmet technological needs, and become more aware of, and willing to exploit, entrepreneurial opportunities (D'Este et al., 2012). And second, because of their capacity to develop new perspectives to address complex problems, interdisciplinary scientists become particularly attractive partners for non-academic actors searching for innovative solutions, in the surge of pressing societal demands (Molas-Gallart et al., 2014). Thus, drawing on this discussion, the proposition based on the interdisciplinary logic would sustain that interdisciplinary scientists are more likely to be involved in university-industry interactions, compared to mono-disciplinary scientists.

As we did for the stardom logic, we contend that the claim of the positive role of interdisciplinary research also requires a number of significant qualifications. First, we contend that interdisciplinary scientists are not equally prone to engagement in each of the three general modes of university-industry interaction: 'entrepreneurial', 'co-production' and 'response' modes. More specifically, because of the context-specific nature of much of the problem-orientation approach of interdisciplinary research, scientists involved in this type of research are inclined to establish close relationships with stakeholders of their research activities. Interaction with stakeholders helps scientists to improve their understanding of complex problems, looking at the challenges faced from different angles and allowing to coming up with novel solutions (Chavarro et al., 2014; Molas-Gallart et al., 2014).

For this reason, we argue that interdisciplinary scientists are more likely to engage in relational modes of university-industry interaction, rather than transactional modes, since scientists involved in interdisciplinary research activities often need to develop long-term relationships with the potential beneficiaries of their research activities. Transactional modes epitomised by technology-transfer approaches are unlikely among interdisciplinary scientist, as the complex problem solving addressed in this type of research is not often susceptible of knowledge codification, which is necessary to operate in the markets for technology (Schartinger et al., 2002).

However, it is rather unclear whether interdisciplinary scientists are more or less likely to be involved in interactions characterised by firm creation. This is so because, while, as discussed above, interdisciplinary scientists may be unlikely to engage in technology transfer modes, they may be susceptible of involvement in firm creation if their breakthrough discoveries require their personal input to industrial partners to reach a further stage of development before inventions become marketable. Despite of this qualification, we put forward the following hypothesis:

> *H4: Interdisciplinary scientists' involvement in university-industry interactions is dependent on the mode of interaction. Interdisciplinary scientists are comparatively more likely to be involved in relational forms of interaction, such as the 'co-production' and response modes, compared to engagement in transactional forms of interaction, such as the 'entrepreneurial' mode*.

In second place, as in the case of star scientists, it is important to note that the relationship between interdisciplinary scientists and engagement in university-industry interactions is likely to be non-linear. This is mainly due to the cognitive and coordination costs associated with the expansion of multiple streams of knowledge when conducting interdisciplinary research. Cognitive costs result from the difficulties to integrate and ever-increasing range of disparate bodies of knowledge, which imply growing efforts to overcome the lack of a common language and shared meanings. In addition, coordination costs are related to the efforts associated to reconciling different norms and managing the organisational challenges of distributed research within highly diverse research teams (Cummings and Kiesler, 2005; Kotha et al., 2013). For this reason, we argue that the degree of engagement in university-industry interactions is likely to increase for higher levels of interdisciplinary research, but this positive relationship may subdue as cognitive and coordination costs impose growing barriers to the capacity of scientists to effectively integrate a larger variety of bodies of knowledge. Building on this argument, we further refine the interdisciplinary logic by putting forward the following hypothesis:

> *H5: Interdisciplinary scientists' involvement in university-industry interactions is likely to be non-linear, showing an inverted U-shape relationship, where the positive effects of interdisciplinary research on university-industry interactions subdue for growing levels of interdisciplinarity*.

Finally, it is important to disentangle the line of causality between interdisciplinary research approaches and university-industry interactions. On the one hand, previous research has shown that scientists who have interacted in the past with non-academic actors are more likely to conduct interdisciplinary research (Carayol and Thi, 2005) or collaborate with research partners from different disciplines (van Rijnsoever and Hessels, 2011). This implies that prior university-industry interactions can be portrayed as an antecedent of scientists' interdisciplinary approaches, as these interactions are likely to raise awareness of research problems that cannot be adequately addressed through a mono-disciplinary focus.

However, our contention here is to argue that the relationship may actually run in the opposite direction: that is, conducting interdisciplinary research is likely to drive interactions with industry, in the absence of previous interaction experience with non-academic partners. In other words, we propose that interdisciplinary research is likely to exert a particularly strong impact on the propensity to engage in university-industry interactions precisely among those scientists who have no previous engagement with industry (or with non-academic partners). This line of causality is congruent with our discussion above regarding the role of boundary spanning and cross fertilisation of ideas in fostering creativity and innovative solutions for complex problems, which characterises interdisciplinary research, and makes interdisciplinary scientists particularly prone to address pressing societal demands and establish close relationships with stakeholders. Following this argument, we put forward the following hypothesis:

H6: The positive role of interdisciplinary scientists in shaping involvement in university-industry interactions will be higher among scientists who had no previous interaction with industry. Thus, we propose a substitution effect between conducting interdisciplinary research and previous interaction experience with industry, on the probability to engage in university-industry interactions.

4. DATA DESCRIPTION AND METHOD

Data source

The main source of data for this study is a large scale survey of all (tenured) scientists in the Spanish Council for Scientific Research (CSIC) - the main public research organization in Spain. The sample consists of 3,199 CSIC scientists who were invited to participate in the on-line survey. CSIC scientists cover all scientific fields, including Biomedicine, Physics, Chemistry, Engineering, and Social Sciences and Humanities (see Table 1, for further details). The survey was conducted between April and May 2011. We achieved a 40% response rate, and 1,295 valid responses. These responses were representative of the population of CSIC scientists in relation to age, gender, and academic rank. However, as Table 1 shows, while generally response rates are similar across scientific fields, some disciplines are overrepresented (e.g. Agriculture, Chemistry and Food Science) while others are significantly under-represented (i.e. Social Sciences and the Humanities).

TABLE 1
Response Rates by Field of Science (N = 1295)

Scientific field	Surveyed Population	Valid Responses	Response Rate
Agriculture Sc.& Tech.	365	191	52% *
Biology & Biomedicine	547	199	36%
Chemistry Sc. & Tech.	381	179	47% *
Food Sc. & Tech.	246	119	48% *
Natural Resources	482	190	39%
Physics Sc. & Tech.	424	163	38%
Social Sc. & Humanities	321	90	28% *
Tech. for New Materials	433	164	38%
Total	**3199**	**1295**	**40%**

* The response rates of these four scientific fields significantly differ (chi-square, $p < 0.05$) when compared to the overall response rate of the other fields in our sample.

We also collected data from secondary sources: (i) administrative data on the socio-demographic characteristics of our population of scientists (i.e. gender, age, academic rank, institute of affiliation), and (ii) bibliometric data from ISI-SCI, to obtain publication and citation profiles, and scientific fields of specialization. Since we combine three different data sources, potential problems of common method bias (CMV) are largely controlled for (Podsakoff et al., 2003). To minimize the possibility of social desirability bias (SDB) (Moorman and Podsakoff, 1992), respondents were guaranteed anonymity. In addition, our respondents hold permanent positions and promotion criteria are mainly driven by demonstration of production with high scientific impact. We think it unlikely therefore that we have biases in scientists' responses to the questionnaire, and particularly to the question on the engagement in interactions with industry, which are key to build our dependent variable measures.

Measures and descriptive statistics

Dependent variables

Our dependent variables are built from the responses to a question asking scientists to report whether they have engaged at least once, over the last three years (2009-2011), in any of the following types of university-business interaction: (i) licensing to firms of patents or other forms of intellectual property rights; (ii) formation of a company; (iii) joint research projects with firms funded by Spanish National research programs; (iv) joint research projects with firms funded by the European Union; (v) consulting activities to firms (defined in the questionnaire as: technological assistance, technical services and technical reports commissioned by firms); and (vi) contract research with firms (projects commissioned by firms, which involve original research).

In order to build our measure for the 'entrepreneurial mode', we have created a variable that takes value 1 if respondents reported that they engaged in items (i) or (ii) (or both), and 0 if they reported that were not active in either (i) or (ii). The measure for 'co-production mode' is built on the responses to items (iii) and (iv), taking the value 1 if respondents reported engagement in any of these items, and zero if respondents reported no participation in those two items. Finally, the measure for 'response mode' is built on responses to items (v) and (vi), and takes value 1 if respondents reported that they engaged in any of these items, and zero if they reported no interaction in these two items. The figures for these three variables are shown in Table 2 below.

TABLE 2
Proportion of scientists in the three modes of university-industry interaction

Scientific field	Entrepreneurial mode	Co-production mode	Response mode	N obs.
Agriculture Sc.& Tech.	14.1	35.1	49.2	191
Biology & Biomedicine	13.1	19.6	39.2	199
Chemistry Sc. & Tech.	15.6	37.4	63.3	179
Food Sc. & Tech.	25.2	43.7	76.5	119
Natural Resources	3.7	23.2	42.6	190
Physics Sc. & Tech.	20.9	35.0	46.0	163
Social Sc. & Humanities	3.3	15.6	30.0	90
Tech. for New Materials	20.1	46.3	62.2	164
Total	**14.5**	**32.1**	**51.0**	**1295**

As Table 2 shows, about half of the scientists report having been involved at least once over the period 2009-2011 in 'response mode' interactions (that is, either consulting or contract R&D, or both). While about a third (i.e. 32%) of our scientists engage in 'co-production mode', and about 14% in the 'entrepreneurial mode'. These proportions show significant variations by field of science, being particularly high in areas of research like Food Science and Chemistry, and comparatively low in Social Sciences and Humanities.

Even though these three modes of university-industry interactions are conceptually distinct (as discussed in our conceptual background) they are unlikely to be totally independent events from an empirical point of view. Table 3 shows that they are far from independent events. Rather the opposite, the proportion of scientists who engage in a given mode is higher, if scientists report having engaged in another mode of interaction. For instance, as Table 3 shows, when scientists engage in entrepreneurial modes (i.e. 188 scientists in our sample), 63% of them also engage in co-production modes; while among the scientists who did not engage in entrepreneurial modes (i.e. 1107 in our sample), only 27% of them reported having participated in co-production modes.

TABLE 3
Proportion of scientists who participate in each of the three modes, conditional on having participated in another mode of university-industry interaction

		Entrepreneurial mode	Co-production mode	Response mode	N obs.
Entrepreneurial mode	Yes		63%	84%	188
	No		27%	46%	1107
Co-production mode	Yes	28%		75%	416
	No	8%		40%	879
Response mode	Yes	24%	47%		661
	No	5%	17%		634

Explanatory variables

We next describe our explanatory variables regarding stardom and interdisciplinarity. We capture the extent to which a scientist can be described as star scientist, by considering the scientific impact of her publications. *Scientific impact* is measured as the average number of citations per paper per year, for all the published papers of a particular scientist. For each paper we computed a score for the average number of citations received per year, from year of publication to 2010, and summed the scores of all the papers of each scientist; we divided this by the total number of publications for that individual. The resulting measure displayed an asymmetric distribution indicating that a few individuals achieve very high scores (10% of our sample of scientists scored 2.5 or above), while the large majority had a score between 0.1 and 2 citations per paper and year. A very small proportion of scientists in our sample (i.e. 4.5%) received zero citations to their work. We log transformed this variable for our empirical analysis (after adding 1 to the original values, in order to retain the cases with zero citations).

To capture the extent to which a researcher can be portrayed as an interdisciplinary scientist, we use a measure of *Interdisciplinary* research based on the diversity of scientific disciplines in which a scientist is involved in their research activities. This measure is derived from the number of ISI subject categories (SC) of each researcher's journal articles. To build this measure, we used the Shannon entropy index which has the advantage that scores depend on both the number of subject categories and the balance in the distribution of publications across subject categories. For instance, scientists whose publications are distributed evenly across subject categories are assigned a higher score than scientists whose publications cover a similar range of subject categories but are unevenly distributed - that is, they are concentrated in a few subject categories. Thus, a higher Shannon score reflects expertise in a wide range of scientific fields. This index can be expressed as:

$$Interdisciplinarity = \sum_{i=1}^{i=N} p_i \ln(1/p_i),$$

where p_i is the proportion of articles corresponding to the *i*th subject category, and N is the number of subject categories covered by the scientist's journal articles.[2] The scores for this measure range from zero to 3.5, following a close to normal distribution with a spike at zero, reflecting large number of scientists whose research is concentrated in a single subject category.

To illustrate the type of information provided by this measure in more detail, we provide the following two contrasting cases from our sample. (i) A scientist who had a score for interdisciplinary research of 2.05, which is close to the mean in our sample of scientists, based on 25 publications assigned to 10 different subject categories, including Applied Physics (11 articles), Materials Science (5 articles), Physical Chemistry (4), Spectroscopy (1) among other subject categories. (ii) A scientist who had the same number of publications (25) but scored zero for interdisciplinary research because all his publications were in one single category (Astronomy & Astrophysics).

We acknowledge that there are many different approaches to capture interdisciplinary research, as pointed out by Wagner et al. (2011), and that the Shannon Index is not without limitations. For instance, it lacks a dimension of distance between disciplines to fully capture diversity (Rafols et al., 2012). However, this measure has been widely used in the literature (Carayol & Thi, 2005), providing a sound point of reference to contrast our results.

[2] Since an article may belong to more than one subject category, we considered the total number of subject categories attached to all the articles of a scientist, and used this number (which might be higher than the total number of papers) to compute the proportion of papers attached to each subject category.

Moderating variables

In accordance with our conceptual framework, we consider two moderating variables in our empirical analysis: the extent of university-industry experience and the extent to which scientists are inspired by the utility and social impact of their research.

University-industry experience is built as a dichotomous variable from the information on each scientists' RD contracts, consulting activities and income from intellectual property rights (i.e. patents) over the period 1999-2008. This information comes from administrative data provided by CSIC. According to this measure, it is important to note that 57% of the scientists who responded to the survey were not involved in any university-industry interaction as principal investigators. It is true that this measure misses possible informal interactions with industry. However, the fact that the figures of past interaction come from external, secondary sources and are quite consistent with the proportion of researchers who report, based on the survey responses, participation in the three modes of interaction, provides credibility to our measure of past interactions with industry.

User-Orientation is built as a dichotomous variable from a question in the survey that asks scientists to report whether they "were inspired by the practical use and applicability of research findings when conducting their research activities". A Likert scale was provided, ranging from 1 (not at all) to 4 (very much). We build our measure by re-coding all respondents who reported the maximum score of the scale (4) as 1s, and 0 otherwise. As the descriptive table (Table 4) shows, about 30% of the scientists in our sample considered that they have a strong 'user orientation', in the sense of being highly inspired by consideration of practical use and applicability of their research, when conducting their research activities.

Control variables

To account for other individual attributes that might be associated with interaction in any of the three modes examined in this study, we considered some alternative individual-level control variables. First, we included socio-demographic characteristics for the scientists in our sample, such as researcher age (Age), gender (whether the researcher is Male), and academic status (i.e. whether the researcher is a Professor). This information was obtained from the administrative data provided by CSIC. Second, motivational aspects are likely to play an important role in shaping the disposition of scientists to participate in university-industry interactions (D'Este and Perkmann, 2011; Lam, 2011). We take account of this by including a number of motivational features connected to the different types of benefits expected by scientists from their interaction with non-academic agents. These expected benefits included: a) fostering the research agenda of the focal scientist (Advancing Research), b) expanding the scientist's professional network (Expanding Network), and c) increasing the scientist's personal income (Personal Income). The first two are computed as three-item scales, the third is measured as a single-item scale. Additionally, we consider two more general types of motivations regarding the main drivers of the scientists' engagement in research activities: Autonomous and Controlled motivations.

Third, we include information on number of articles per scientist (i.e. log transformation of the total number of papers, *Number Publications*), and average number of co-authors in the scientists' publications (i.e. log transformation of average number of co-authors, *Average N^o Co-authors*). Finally, we include a number of controls for the institutional environment in which the scientist operates. Drawing on information from the responses to the survey, we built a measure of institutional climate to capture the extent to which scientists consider that their research institute offers a climate supportive of knowledge transfer activities, *Supportive Climate*. We also consider a set of dummy variables to control for the scientific disciplines in our sample of scientists (the eight fields of science reported in Table 1). Table 4 presents descriptive statistics and pairwise correlations for all the variables in our analysis.

TABLE 4
Descriptive Statistics and Correlation Matrix (N = 1213)

		mean	sd	Min	max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Entrepr.mode	0.148	0.356	0.000	1.000	1.000																	
2	Co-prod.mode	0.324	0.468	0.000	1.000	0.271*	1.000																
3	Response mode	0.515	0.500	0.000	1.000	0.261*	0.323*	1.000															
4	Scientific impact	1.354	1.011	0.000	9.183	0.011	-0.022	-0.071*	1.000														
5	Interdisciplinarity	1.680	0.644	0.000	3.482	0.107*	0.110*	0.120*	0.130*	1.000													
6	U-I Experience	0.432	0.496	0.000	1.000	0.156*	0.236*	0.290*	-0.067*	0.153*	1.000												
7	User orientation	0.322	0.467	0.000	1.000	0.160*	0.146*	0.226*	-0.070*	0.091*	0.180*	1.000											
8	Advancing research	1.108	0.522	0.000	2.000	0.039	0.056	0.154*	0.008	0.023	0.030	0.153*	1.000										
9	Expanding network	0.858	0.508	0.000	2.000	0.073*	0.084*	0.134*	-0.042	-0.023	0.035	0.183*	0.581*	1.000									
10	Personal income	0.262	0.552	0.000	2.000	-0.009	-0.029	0.024	-0.006	-0.072*	-0.025	0.057*	0.263*	0.230*	1.000								
11	Controlled mot.	2.846	0.711	1.000	4.000	0.049	0.043	0.046	0.006	-0.044	0.033	0.054	0.103*	0.125*	0.377*	1.000							
12	Autonomous mot.	3.645	0.475	1.667	4.000	-0.002	-0.022	-0.031	0.077*	-0.079*	-0.012	-0.092*	0.165*	0.143*	0.076*	0.247*	1.000						
13	Age	49.771	8.244	31.000	70.000	0.009	-0.010	0.031	-0.102*	0.072*	0.244*	-0.002	-0.016	-0.050	0.004	-0.023	-0.100*	1.000					
14	Gender (male = 1)	0.657	0.475	0.000	1.000	0.062*	0.051	0.050	0.059*	0.048	0.052	0.021	-0.178*	-0.191*	0.019	0.041	0.036	0.096*	1.000				
15	Professor	0.232	0.422	0.000	1.000	0.057*	0.058*	0.056	0.107*	0.088*	0.215*	0.040	-0.031	-0.027	0.005	0.061*	0.088*	0.435*	0.154*	1.000			
16	Supportive climate	2.153	1.778	0.000	4.000	0.108*	0.106*	0.139*	-0.035	0.035	0.128*	0.100*	0.122*	0.153*	-0.020	0.024	-0.008	0.022	0.028	-0.003	1.000		
17	N. Publications	32.590	32.047	1.000	286.0	0.086*	0.103*	0.135*	0.167*	0.398*	0.165*	-0.022	-0.035	-0.086*	-0.071*	-0.005	-0.054	0.136*	0.066*	0.383*	-0.007	1.000	
18	Avg. n. co-authors	7.669	44.872	0.000	1183.5	-0.007	-0.016	-0.017	0.097*	-0.050	-0.039	-0.034	0.035	-0.033	-0.037	0.006	-0.035	-0.039	-0.020	-0.015	0.034	0.073*	1.000

* $p<0.05$

Method

Since an academic scientist can use multiple channels of university-industry interactions, the three modes of interaction are not independent to each other. For this reason, our estimation model should allow the error terms of the equations for each dependent variable to be correlated. We us use a simulated maximum likelihood approach to estimate the coefficients, using a Multivariate probit regression model (mvprobit command in Stata) (see Abreu and Grinevich, 2013; D'Este et al., 2012).

5. RESULTS

We investigate how scientific impact and interdisciplinary research affect the propensity of scientists to engage in the three modes of university-industry interactions: entrepreneurial, co-production and response modes. The first set of results is presented in Table 5. The estimates displayed in Table 5 provide a test for our hypotheses 1, 2, 4 and 5. As anticipated in H1, scientists with a high scientific impact (i.e. star scientists) are not more likely to engage in each of the three modes of interaction. In fact, for each mode, the relationship with scientific impact is different. We observe a U-shape curvilinear relationship between scientific impact and the propensity to participate in the entrepreneurial mode, where the highest probabilities of participation happen at either low or high levels of scientific impact. This is in contrast with the relationship between scientific impact and the propensity to engage in the response mode, where our results indicate the existence of a negative relationship. It is also in contrast with the results for the relationship between scientific impact and participation in the co-production mode, where we observe no statistically significant association between the two. These different patterns are illustrated in Figure1.

TABLE 5
Multivariate Probit Regression Models: Effects of Scientific Impact and Interdisciplinarity on Entrepreneurial, Co-Production and Response Modes

	Scientific impact			Interdisciplinarity			Full model		
	(1) Entrepr. mode	(2) Co-prod. mode	(3) Response mode	(4) Entrepr. mode	(5) Co-prod. mode	(6) Response mode	(7) Entrepr. mode	(8) Co-prod. mode	(9) Response mode
Scientific impact	-0.162**	0.002	-0.147**				-0.150**	0.010	-0.135**
	(0.07)	(0.06)	(0.06)				(0.07)	(0.06)	(0.06)
Scientific impact^2	0.115***	-0.004	0.020				0.119***	-0.002	0.015
	(0.04)	(0.03)	(0.03)				(0.04)	(0.03)	(0.03)
Interdisciplinarity				0.192***	0.143***	0.087*	0.202***	0.144***	0.080
				(0.06)	(0.05)	(0.05)	(0.06)	(0.05)	(0.05)
Interdisciplinarity^2				0.075**	0.046	0.080***	0.070**	0.046	0.076***
				(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
U-I Experience	0.350***	0.587***	0.643***	0.374***	0.576***	0.652***	0.342***	0.578***	0.641***
	(0.10)	(0.09)	(0.08)	(0.10)	(0.09)	(0.08)	(0.10)	(0.09)	(0.08)
User orientation	0.376***	0.210**	0.386***	0.366***	0.198**	0.400***	0.367***	0.198**	0.392***
	(0.10)	(0.09)	(0.09)	(0.10)	(0.09)	(0.09)	(0.10)	(0.09)	(0.09)
Advancing research	-0.005	0.014	0.272***	-0.046	0.002	0.257***	-0.026	0.002	0.257***
	(0.12)	(0.10)	(0.09)	(0.12)	(0.10)	(0.09)	(0.12)	(0.10)	(0.09)
Expanding network	0.198	0.190*	0.128	0.218*	0.194*	0.133	0.207*	0.196**	0.135
	(0.12)	(0.10)	(0.10)	(0.12)	(0.10)	(0.10)	(0.12)	(0.10)	(0.10)
Personal income	-0.138	-0.147*	-0.024	-0.127	-0.139*	-0.020	-0.128	-0.140*	-0.016
	(0.10)	(0.08)	(0.08)	(0.10)	(0.08)	(0.08)	(0.10)	(0.08)	(0.08)
Controlled motivation	0.070	0.063	0.025	0.038	0.055	0.010	0.053	0.054	0.013
	(0.08)	(0.06)	(0.06)	(0.08)	(0.06)	(0.06)	(0.08)	(0.06)	(0.06)
Autonomous motivation	0.033	-0.061	-0.080	0.058	-0.034	-0.062	0.077	-0.034	-0.054
	(0.11)	(0.09)	(0.09)	(0.11)	(0.09)	(0.09)	(0.12)	(0.09)	(0.09)
Age	-0.008	-0.012**	-0.007	-0.007	-0.013**	-0.004	-0.008	-0.013**	-0.007
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Gender (male = 1)	0.284***	0.217**	0.274***	0.287***	0.217**	0.272***	0.285**	0.217**	0.279***
	(0.11)	(0.09)	(0.09)	(0.11)	(0.09)	(0.09)	(0.11)	(0.09)	(0.09)
Professor	0.038	0.108	0.006	0.071	0.131	-0.032	0.070	0.129	-0.002
	(0.13)	(0.11)	(0.11)	(0.13)	(0.11)	(0.11)	(0.13)	(0.11)	(0.11)
N. Publications	0.153**	-0.003	0.085*	-0.012	-0.059	0.034	0.068	-0.061	0.069
	(0.06)	(0.05)	(0.05)	(0.06)	(0.05)	(0.05)	(0.07)	(0.05)	(0.05)
Avg. num co-authors	0.089	0.079	-0.011	0.051	0.066	-0.064	0.065	0.064	-0.022
	(0.09)	(0.08)	(0.07)	(0.09)	(0.08)	(0.07)	(0.09)	(0.08)	(0.07)
Supportive climate	0.077***	0.042*	0.053**	0.074***	0.040*	0.050**	0.077***	0.040*	0.051**
	(0.03)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)
Scientific field (dummies)	Included	Included	Included	Included	Included	Included	Included	Included	Included
Constant	-2.455***	-0.955*	-0.813	-1.957***	-0.885*	-0.872*	-2.382***	-0.882	-0.879*
	(0.66)	(0.53)	(0.51)	(0.65)	(0.53)	(0.51)	(0.67)	(0.54)	(0.52)
N	1213			1213			1213		
Log Likelihood	-1848.3			-1842.9			-1835.7		
Wald Chi^2	368.56***			374.48***			386.88***		
LR test χ^2 ($\rho_{21}=\rho_{31}=\rho_{32}=0$)	126.344***			121.673***			123.506***		

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$ (two-tailed)

FIGURE 1

Effects of scientific impact in the probability to participate in Entrepreneurial, Co-production and Response modes.

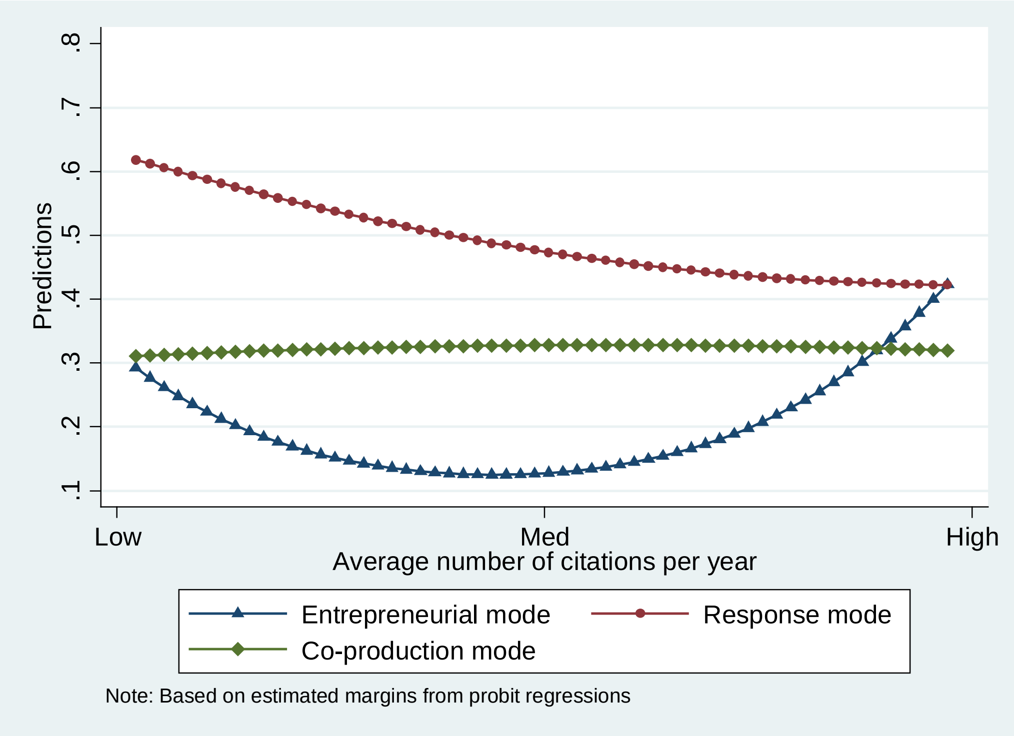
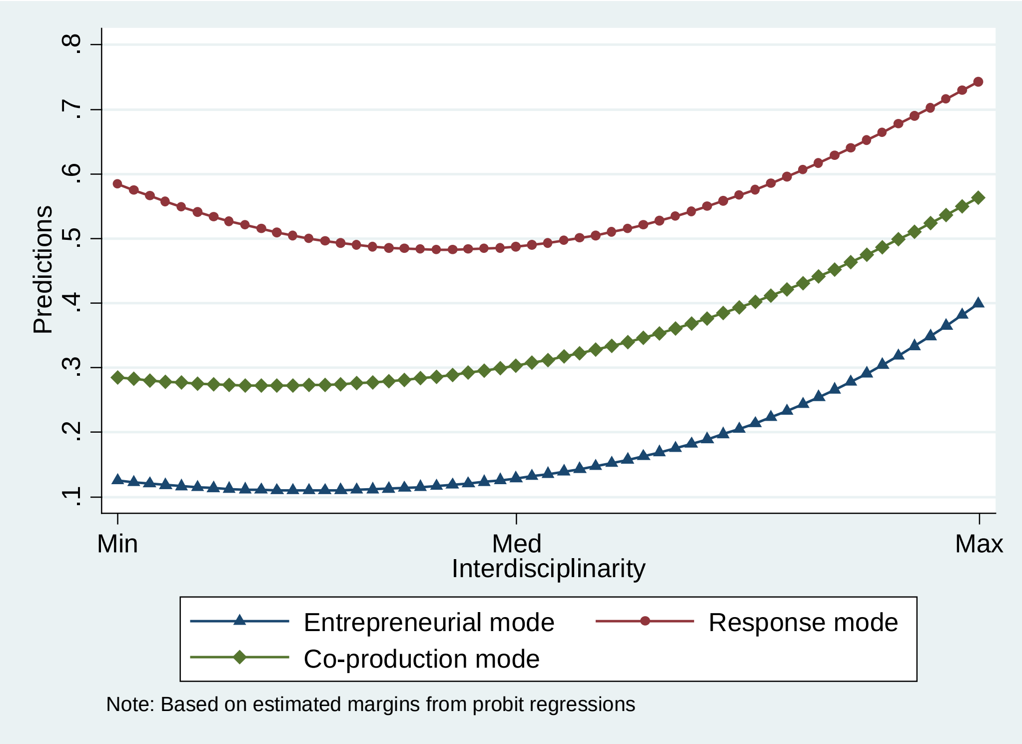


FIGURE 2

Effects of interdisciplinarity in the probability to participate in Entrepreneurial, Co-production and Response modes.



We do not observe, as put forward in Hypothesis 2, that a positive relationship emerges for higher levels of scientific impact, with regards to all modes of interaction. We only observe this for the case of the entrepreneurial mode: in this case there is an inflection point beyond which larger levels of scientific impact are associated with a higher probability of involvement.

Regarding interdisciplinary research, the results in Table 5 provide strong evidence of a positive relationship between conducting interdisciplinary research and participation in all the three modes of university-industry interactions examined. However, we do not observe a particularly strong effect of interdisciplinarity on relational modes (as compared to more transactional modes): in both cases, transactional and relational modes, we find a positive and significant relationship between interdisciplinary research and engagement. Thus, the results in Table 3 lead us to reject H4. Moreover, while we do observe a curvilinear relationship between interdisciplinary research and involvement in the entrepreneurial and response modes, this curvilinear relationship is more of a J-shape style than the inverted U-shape hypothesised (see Figure 2). In other words, the probability of engagement increases with interdisciplinary research in the three modes of university-industry interaction, and this positive association is increasing for higher levels of interdisciplinarity in the cases of entrepreneurial and response modes. This again is contrary to our Hypothesis 5 that had anticipated an exhaustion of the positive effects of interdisciplinary research due to integration and coordination costs.

In order to address our hypothesis H3 and H6, we have replicated the same analysis considering interaction terms between scientific impact and user orientation, on the one hand, and interdisciplinary research and university-industry experience, on the other. The results are reported in Table 6.

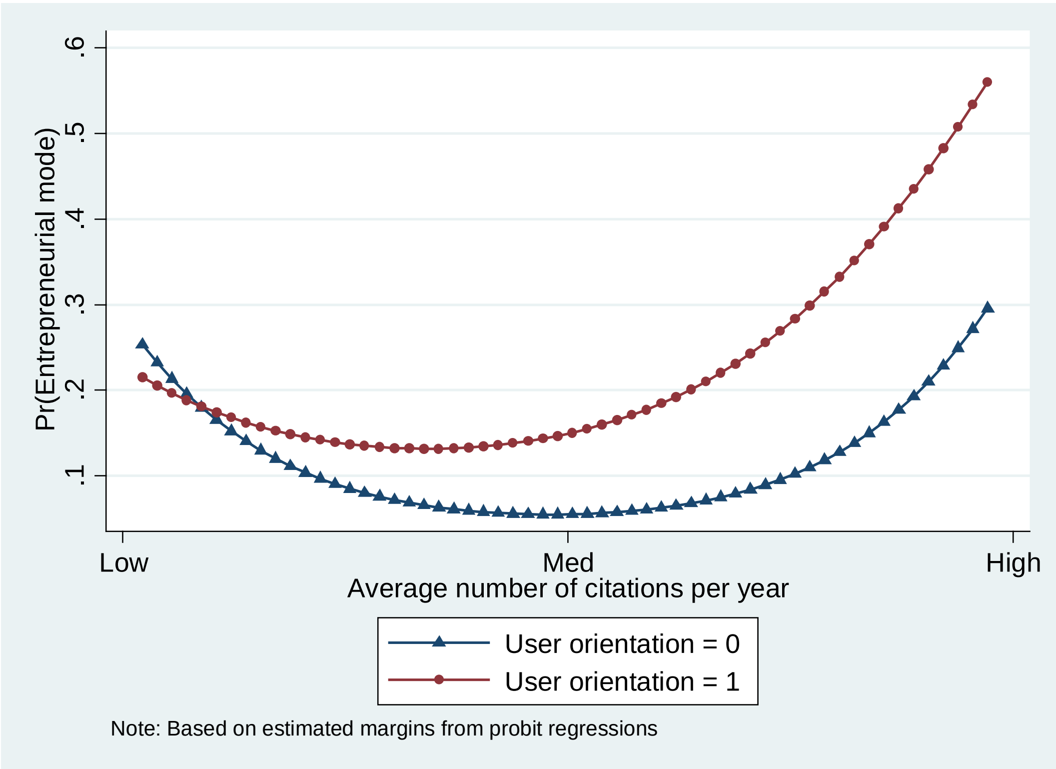
TABLE 6
Multivariate Probit Regression Models for Interaction Effects

	Scientific impact			Interdisciplinarity		
	Entrepr. mode	Co-prod. Mode	Response mode	Entrepr. mode	Co-prod. mode	Response mode
Scient.impact*User orient.	0.190*	0.178*	0.181*			
	(0.11)	(0.10)	(0.09)			
Scient.impact^2*User orient.	-0.026	0.004	-0.040			
	(0.07)	(0.06)	(0.06)			
Interdiscip.*U-I experience				-0.205**	-0.026	0.022
				(0.10)	(0.09)	(0.09)
Interdiscip.^{2}*U-I experience				0.033	0.057	0.024
				(0.07)	(0.06)	(0.06)
Scientific impact	-0.214***	-0.041	-0.180***	-0.149**	0.011	-0.133**
	(0.08)	(0.07)	(0.06)	(0.07)	(0.06)	(0.06)
Scientific impact2	0.127***	-0.004	0.024	0.123***	0.001	0.015
	(0.05)	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)
Interdisciplinarity	0.207***	0.150***	0.082	0.295***	0.153**	0.071
	(0.06)	(0.05)	(0.05)	(0.08)	(0.07)	(0.06)
Interdisciplinarity2	0.070**	0.047	0.074***	0.053	0.021	0.066*
	(0.03)	(0.03)	(0.03)	(0.05)	(0.04)	(0.04)
U-I Experience	0.352***	0.588***	0.653***	0.354***	0.528***	0.614***
	(0.11)	(0.09)	(0.09)	(0.13)	(0.10)	(0.10)
User orientation	0.376***	0.184*	0.421***	0.354***	0.192**	0.395***
	(0.12)	(0.10)	(0.10)	(0.10)	(0.09)	(0.09)
Advancing research	-0.021	0.010	0.265***	-0.012	0.014	0.261***
	(0.12)	(0.10)	(0.10)	(0.12)	(0.10)	(0.10)
Expanding network	0.205*	0.188*	0.128	0.195	0.188*	0.131
	(0.12)	(0.10)	(0.10)	(0.12)	(0.10)	(0.10)
Personal income	-0.131	-0.138*	-0.014	-0.126	-0.138*	-0.015
	(0.11)	(0.08)	(0.08)	(0.11)	(0.08)	(0.08)
Controlled motivation	0.049	0.050	0.008	0.048	0.052	0.014
	(0.08)	(0.06)	(0.06)	(0.08)	(0.06)	(0.06)
Autonomous motivation	0.066	-0.035	-0.064	0.091	-0.028	-0.057
	(0.12)	(0.09)	(0.09)	(0.12)	(0.09)	(0.09)
Age	-0.008	-0.013**	-0.006	-0.008	-0.013**	-0.007
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Gender (male = 1)	0.291***	0.223**	0.284***	0.289***	0.218**	0.278***
	(0.11)	(0.09)	(0.09)	(0.11)	(0.09)	(0.09)
Professor	0.070	0.138	0.007	0.074	0.137	0.004
	(0.13)	(0.11)	(0.11)	(0.13)	(0.11)	(0.11)
N. Publications	0.068	-0.063	0.067	0.076	-0.057	0.069
	(0.07)	(0.05)	(0.05)	(0.07)	(0.05)	(0.05)
Avg. num co-authors	0.059	0.058	-0.034	0.079	0.067	-0.027
	(0.10)	(0.08)	(0.08)	(0.10)	(0.08)	(0.07)
Supportive climate	0.078***	0.041*	0.052**	0.075***	0.040*	0.051**
	(0.03)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)
Scientific field (dummies)	Included	Included	Included	Included	Included	Included
Constant	-2.343***	-0.860	-0.832	-2.482***	-0.895*	-0.853
	(0.67)	(0.54)	(0.52)	(0.67)	(0.54)	(0.52)
N	1213			1213		
Log Likelihood	-1830.6			-1832.8		
Wald Chi^2	394.02			389.79		
LR test χ^2 ($\rho_{21}=\rho_{31}=\rho_{32}=0$)	121.838			124.741		

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$ (two-tailed).

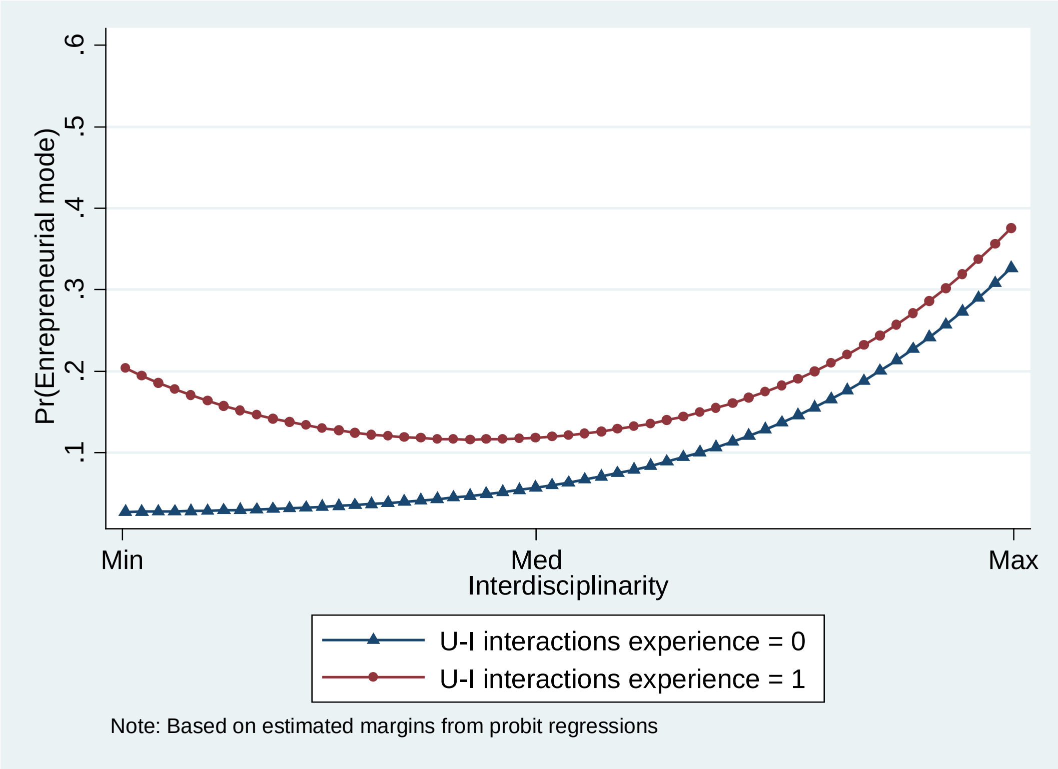
Regarding hypothesis 3, we find some support to the argument that scientific impact has a stronger effect on the participation, in every mode of university-industry interaction, when the user-orientation of research is high, since we observe that the interaction terms between the linear term of scientific impact and user orientation is always positive with respect to the three modes of interaction. However, these interaction terms are only weakly significant - statistically significant at the 10% level. Figure 3 represents the relationship between scientific impact and entrepreneurial mode for scientists with low and high user orientation.

FIGURE 3
Effects of User Orientation in the relationship between Scientific Impact and the probability of participating in Entrepreneurial Mode



Regarding hypothesis 6, we only find strong evidence of an interplay between experience in university-industry interactions and interdisciplinary research, for the case of the entrepreneurial mode. That is, in this case results support the argument that interdisciplinary research exerts a stronger effect on participation in the entrepreneurial mode in the case of scientists who have no previous experience of university-industry interactions. For the other two modes of interaction, we reject our hypothesis of a negative interplay between interdisciplinary and experience. Figures 3 and 4 provide a visual representation of these results. The interaction effect between interdisciplinarity research and previous knowledge transfer experience in predicting entrepreneurial mode is shown in Figure 4.

FIGURE 4
Effects of knowledge transfer experience in the relationship between Interdisciplinarity and the probability of participating in Entrepreneurial Mode



6. DISCUSSION AND CONCLUSIONS

This study examines two contrasting views of the antecedents of university-industry interactions among academic scientists: the star scientist logic versus the interdisciplinary scientist logic. According to the star scientist approach, researchers who conduct leading-edge research and enjoy a high degree of visibility in their academic communities are particularly likely to generate breakthrough discoveries susceptible of a high technological impact that provide opportunities for commercial exploitation. Drawing on this logic, star scientists are expected to be more prone to engage in university-industry interactions, than academic peers who do not enjoy comparable levels of scientific impact in their research activities. In contrast, the interdisciplinary scientist logic would claim that researchers who conduct research characterised by the integration of multiple disciplines and bodies of knowledge, are particularly likely to identify and generate breakthrough ideas that challenge existing wisdom, coming out with new perspectives to address unsolved problems faced by academic and non-academic communities. Following this rationale, interdisciplinary scientists would be more prone to engage in university-industry interactions than academic peers who do not enjoy comparable levels of interdisciplinarity in their research activities.

This study has examined the impact of these two contrasting logics by investigating the extent to which they are associated to scientists' engagement in three distinct modes of university-industry interactions: entrepreneurial, co-production and response modes. We argue that it is critical to separate these different types of university-industry interactions as they respond to very distinct profiles in terms of: (i) type of contractual agreement (contractual vs. relational) and (ii) form of finalization (targeted vs. open ended). Our main findings can be summarised and discussed as follows.

First, our results show that the effect of scientific impact on the probability of engagement in university-industry interactions is contingent on the mode of interaction. That is, we find no positive or negative effect that works for all modes of interaction, but instead, we observe distinct effects depending on the interaction mode. More specifically, we find a positive effect in the case of the entrepreneurship mode, but only beyond a critical level of scientific impact. In contrast, we find no significant effect of stardom on the co-production mode, and a negative effect of stardom on the response mode. This suggests that the star scientist logic works only for the entrepreneurship mode of engagement, which is characterised by a science push approach, where the academic interest in the commercial exploitation is driven by scientific discovery and breakthroughs from research findings.

On the contrary, our results indicate that interdisciplinary research has a more horizontal, transversal positive impact that runs across-the-board for all modes of university-industry interaction. Interdisciplinary scientists are more likely to participate in all three modes: entrepreneurship, co-production and response modes. This positive effect is actually not exhausted for increasing levels of interdisciplinarity, as we had anticipated due to the cognitive limitations of integrating multiple bodies of knowledge. Rather, the evidence points out that there is an exponentially growing effect of interdisciplinary research in the cases of entrepreneurship and response modes.

Second, we find that the effect of stardom on the propensity to interact in university-industry interactions can be enhanced by the scientists' awareness about the usability of their research. More specifically, there is a positive effect of scientific impact on the three modes of interaction when scientists are particularly aware of the potential use of their research findings. This is especially interesting in the cases of response and co-production modes, for which, in absence of such a user-orientation, we find a negative and a non-significant effect of scientific impact, respectively.

Third, since interdisciplinarity can be a result of previous interaction with industry, we have investigated the presence of reverse causality with regards to the relationship between interdisciplinary research and engagement in university-industry interaction. On the one hand, our measure of interdisciplinarity refers to the research profile of scientists in the past, and we have controlled for past involvement of scientists in interactions with industry in all our regressions. On the other hand, we have examined the interaction between interdisciplinary and past involvement in interactions with industry, finding that there is no significant interaction or that this is statistically significant and negative in the case of the entrepreneurship mode. Thus, we find that the impact of interdisciplinarity on participation in entrepreneurship is higher among those individuals who had no previous interaction with industry. These results provide further support for our argument about interdisciplinarity as an antecedent of university-industry interactions.

Finally, these findings have some interesting implications for research policy and university management. From a management perspective, it raises the argument about the importance to consider the variety of interaction modes in their own right. Even though the three modes of interaction are not fully independent from each other, they are governed by different mechanisms. Thus, the type of institutional support to encourage or facilitate the entrepreneurship mode has very little in common with those required to foster a co-production mode or a response mode. This study has investigated the antecedents of these three modes, showing that the effect of scientific impact on each mode differs greatly.

From a research policy perspective, there are a number of implications from this study. Given the strong influence of conducting interdisciplinary research on university-industry interactions, science and education policies oriented to foster interdisciplinary training backgrounds and mixed research teams should we welcomed. Indeed, our findings suggest that the encouragement of high scientific impact in research activities should be matched with a stronger support for interdisciplinary research, which is likely to complement research excellence in the pursuit of a higher appreciation for the usability of research findings and involvement in multiple modes of university-industry interactions.

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