Sourcing upstream or downstream? Exploring knowledge-based antecedents of academic entrepreneurship

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Abstract
This paper examines two contrasting knowledge-based antecedents of entrepreneurship and technology transfer among scientists in public research institutions. 'Upstream knowledge sources', which refer to insights for commercial opportunities gained as a result of high impact scientific contributions; and 'downstream
knowledge sources’, which refer to knowledge gained through researchers’ direct interactions with research beneficiaries. We find that downstream sources are associated with the two commercialization pathways examined: i.e. firm creation and technology licensing; while upstream sources are mainly associated with entrepreneurship (i.e. firm creation). Moreover, we find no evidence of a complementary relationship between upstream and downstream sources on academic entrepreneurship; while we find a substitution effect in the case of technology transfer. Our findings suggest the existence of three co-existing, alternative archetypes of academic scientists involved in firm creation: star scientists, engaged scientists and bridging scientists. In contrast, we find that downstream knowledge sources constitute the dominant knowledge-base antecedent to technology licensing.
1. Introduction

Scientists' engagement in entrepreneurial and technology transfer activities has motivated an extensive track of research on the underlying mechanisms that drive academic entrepreneurship and commercialisation behaviour (Agarwal and Shah, 2014; Siegel and Wright, 2015). Research on entrepreneurship suggests that idiosyncratic prior knowledge resources affect the capacity of individuals to identify and successfully exploit entrepreneurial opportunities, and represent a fundamental antecedent of entrepreneurial behaviour (Adams et al., 2015; Shane, 2000). Indeed, entrepreneurship research has convincingly argued that combining ‘technological’ and ‘market’ knowledge enhances the capacity of actors to identify and exploit entrepreneurial opportunities, thus favouring entrepreneurial behaviour and academic entrepreneurship in particular (Shane and Venkataraman, 2000; Fini et al., 2012).

Drawing on this knowledge-based approach, this study aims to advance understanding on academic entrepreneurship and technology transfer research by contrasting the relative influence of technological and market knowledge sources as antecedents of technology commercialisation by academic scientists. More specifically, we put forward the following propositions. First, we contend that high-impact scientific contributions (i.e. upstream knowledge sources) and market knowledge about the context of application (i.e. downstream knowledge sources) can be portrayed as two alternative sources of knowledge underpinning the commercial exploitation of academic inventions. We argue that upstream and downstream knowledge sources have a distinct influence on entrepreneurial and technology transfer behaviours: while academic entrepreneurship is likely to be fundamentally associated with upstream knowledge sources, technology transfer is expected to be dominantly associated with downstream knowledge sources.

Second, we contribute to entrepreneurship research by examining the contingencies associated to the reinforcing effects of technological and market knowledge on entrepreneurial behaviour (Adams et al., 2015; Agarwal and Shah, 2014). We argue that...
the interplay between upstream and downstream knowledge sources work in opposite
directions regarding the two types of commercialisation pathways analyzed in this study.
We expect a complementary relationship between the two sources of knowledge in the
case of firm creation, such that downstream sources of knowledge are expected to
positively moderate the relationship between upstream knowledge sources and firm
creation. Conversely, we expect a substitution effect in the case of technology transfer,
such that downstream knowledge sources will compensate for the absence (or low
presence) of upstream knowledge sources.

This study examines 1,200 scientific researchers who are representative of the population
of scientists in the Spanish National Research Council (CSIC), the largest public research
organization in Spain, to test our hypotheses about the relationship between knowledge-
based antecedents and technology commercialisation behaviour. Our dataset allows us to
control for distinct fields of science and it provides detail information about the specific
organisational affiliation of scientists. In addition, survey data has been combined with
secondary sources in order to gather information about individual scientific performance
and levels of interaction with non-academic actors.

Our results challenge some widely held assumptions in entrepreneurship research. On the
one hand, the conception that academic involvement in entrepreneurship and technology
transfer mainly respond to a science-driven, technology-push approach. On the other hand,
the notion that there is a strong complementarity between technology and market
knowledge underpinning commercialisation and entrepreneurial action. This study shows
that the sources of knowledge underlying firm creation are fundamentally heterogeneous
across the population of academic scientists: i.e. some scientists mainly drawing on high
impact discoveries while others mainly relying on market knowledge sources. In contrast,
academic scientists involved in technology licensing are particularly driven by market-
based, downstream knowledge sources, suggesting that scientists who have greater
interaction with user communities are particularly likely to engage in technology transfer
activities, even in the absence of a track record of high-impact or breakthrough scientific
discoveries.
2. Literature Review and Hypotheses

2.1. Markets for invention and two mechanisms of commercialisation

Universities and public research organisations (PROs) commercialise inventions that originate in research activities through two dominant routes: (i) by licensing the technology to incumbent firms, and (ii) by establishing a company to develop and commercialise the technology (typically founded by the academic inventors of the technology) (Shane, 2002; Powers and McDougall, 2005). In the last decades there has been a sharp increase in the number of licenses and spin-offs as a response to university efforts to enhance revenue streams and to demonstrate economic returns from publicly funded research (Powers and McDougall, 2005; Thursby et al, 2011).

Existing research has shown that technology licensing (in exchange of up-front fees, royalties or a combination of both) is the most frequent commercialisation mechanism, well-above and beyond spin-off formation (Markmann et al, 2005; Thursby et al., 2001). This balance in favour of technology licensing is not surprising since, as argued by Shane (2002), markets for inventions and technologies provide, in principle, the most efficient allocation of skills and physical resources. Market-mediated transactions allow for academic scientists to specialise on the invention of the technology, while companies with expertise in manufacturing and marketing would focus on the commercialisation of the new technology. Thus, markets for invention potentially allows for an effective exploitation of market opportunities to be gained from trade, leading to a first-best choice for technology commercialisation from university research (Shane, 2002).

However, market-mediated transactions are contingent on the appropriate functioning of markets for inventions. Unfortunately, information problems often prevent markets for inventions to work effectively. There are two main information problems that undermine the effectiveness of markets for inventions. On the one hand, the difficulty to establish contracts that provide appropriate information to the parties involved in order to avoid opportunistic behaviour (Shane, 2002). Setting complete contracts is particularly challenging in the context of university-based technologies, which tend to be at an early stage of development, making it difficult to set the terms of what exactly is to be transferred (Thursby et al., 2001; Markman et al., 2005). On the other hand, market-based transactions involving new technologies may be conducive to the transfer of information but not necessarily to the transfer of knowledge. Since knowledge is largely embodied in
people and new technologies may not be effectively developed without the active participation of the original inventors, the effectiveness of disclosure and transactions through patents as a mechanism for the effective transfer of technology is considerably limited (Zucker and Darby, 1996).

In the presence of these information problems for the effective functioning of markets for inventions, the commercialisation of university-based technologies involves more nuanced alternatives than those assumed by a simple market-mediated transaction approach. These nuances include the negotiation of detailed contingencies in technology licensing agreements, such as the combination of output-based payments and up-front fees in license agreements, to account for the substantial uncertainty about the value of inventions (Thursby et al., 2001). It also embraces the decision of inventors to found firms to develop and commercialise their technologies, as a response to the difficulty of finding a suitable client with either the competences or the willingness to develop a technology that is often far from a marketable product. Indeed, the choice of inventors to create their own company has been portrayed in the literature as a second-best solution for technology commercialisation, since it is often a response to a failure in markets for knowledge (Shane, 2002), and academic inventors are often reluctant to assume the managerial responsibilities associated with becoming a company founder (Jain et al., 2011).

2.2. Knowledge sources of entrepreneurship and technology transfer
Research on entrepreneurship has stressed the importance of the differential knowledge background of individuals as a critical factor underlying the identification and exploitation of entrepreneurial opportunities (Adams et al., 2015; Agarwal and Shah, 2014; Shane, 2000). This theoretical approach builds on the concept of information asymmetries, suggesting that differences in prior knowledge are at the heart of the individual capacity to identify and exploit entrepreneurial opportunities. As proposed by Shane (2000, p. 449), “the possession of idiosyncratic information allows people to see particular opportunities that others cannot see” and contributes to explain why certain individuals are likely to become entrepreneurs.

We draw upon this stream of entrepreneurship research to examine the antecedents of academic entrepreneurship and technology transfer, and we contribute to the entrepreneurship and university-business interaction literatures along several critical
dimensions. First, we examine contrasting perspectives on what constitutes the dominant source of knowledge for entrepreneurship and technology transfer among academic scientists. On the one hand, a logic based on upstream knowledge sources, which portrays technological knowledge and breakthrough discovery as the dominant source of idiosyncratic information and knowledge that scientists possess for the identification and exploitation of entrepreneurial opportunities (Agarwal and Shah, 2014; Zucker et al., 1998). On the other hand, a logic based on downstream knowledge sources, which portrays market knowledge and proximity to user needs as the dominant source of scientists’ idiosyncratic information and knowledge for the identification and exploitation of entrepreneurial opportunities (Adams et al., 2015; Shane, 2000).

**Upstream knowledge sources as antecedents of academic entrepreneurship and technology transfer**

The involvement of academic scientists in entrepreneurship and technology transfer has been often associated with their prior contributions to breakthrough scientific discoveries. Indeed, scientists who have significantly contributed to outstanding scientific discoveries, and have achieved a prominent position within the academic community in terms of reputation and recognition (i.e. star scientists), have been found to be particularly susceptible to become entrepreneurs. This pattern is exemplified paradigmatically by the case of university biotechnology spin-offs, as Zucker et al. (1998) have pointed out: the participation of university star scientists was fundamental in the emergence and commercial success of biotechnology companies in the US, based on pioneering inventions from star scientists who were among the founders of many newly born biotechnology enterprises. Similarly, Lowe and Gonzalez-Brambila (2007) have found that university faculty entrepreneurs are likely to be outstanding scientific contributors within their fields, compared to their graduate school peers or faculty population in general.

This characterisation of academic entrepreneurship corresponds to a science-push perspective where academic scientists benefit from insights gained through scientific advances to identify and commercially exploit inventions with market potential. This science driven approach is consubstantial with the claim that ‘star scientists’ are particularly well-equipped to become entrepreneurs, and with the logic of upstream (science-driven) knowledge sources as underlying the commercialisation behaviour of academic scientists.
There are two highly interconnected reasons that contribute to explain this upstream knowledge-base logic for scientists’ commercialisation behaviour. The first argument is that high impact scientific discoveries bear the potential to expand the available technological opportunities by widening the pool of inventions with potentially high commercial value. Academic inventors are potentially contributors to the pool of new research techniques and technologies, helping to expand the horizon of profitable business opportunities available to firms. As pointed out by Zucker and Darby (1996): “While relatively few mature industries are driven by technological opportunity in the form of basic scientific breakthroughs, the emergence phase of important industries frequently is so driven” (:12715).

The second argument is associated with the tacit nature of knowledge underlying scientific discoveries. Knowledge related with science-based discoveries (including knowledge about the capacity to replicate particular scientific results) must be seen as embodied in the scientists responsible for the discovery (Zucker and Darby, 1996). Accordingly, the commercial exploitation of scientific discoveries that are associated with inventions with a high market potential, might be restricted to the direct participation of inventors in the further development of the technologies. This is not only reminiscent of academic entrepreneurship - that is, scientists becoming entrepreneurs in order to commercially exploit a particular invention - but also closely connected with the role that academic inventors often play in ensuring the further development of a technology within the context of a technology licensing agreement (Jensen and Thursby, 2001).

Drawing on the preceding discussion, we put forward the following hypothesis:

**Hypothesis 1a.** Upstream sources of knowledge are positively associated with academic entrepreneurship and technology transfer, such that: scientists who have a track record of high impact scientific contributions are more likely to engage in firm creation and technology licensing.

The science-driven rationale underlying the upstream knowledge-base antecedents of entrepreneurship and technology transfer also highlights the embryonic nature of scientific inventions. In fact, one of the main reasons pointed out in previous studies regarding the decision to set up a spin-off company is related with the early stage of development of the technology to be exploited (Rizzo, 2015; Markman et al., 2005). University inventions are
frequently distant from applications or commercial use when they are licensed. Thursby et al. (2001) have demonstrated that a high proportion of inventions disclosed by university scientists are at very early phase of development. These authors show that about 45% of the inventions licensed were at a proof-of-concept stage, while only 15% of the inventions licensed had demonstrated manufacturing feasibility. This early phase development of university inventions imply that licensed inventions often require the cooperation of inventors for further development of the technologies licensed and for their commercial exploitation.

The embryonic nature of university inventions do not prevent their licensing but it represents a significant obstacle for the effective functioning of markets for inventions. The early phase of development imposes restrictions to the direct transfer from the academic to the industrial environment since it raises uncertainties about the commercial feasibility of the underlying technology and it limits the range of industry partners willing to license the intellectual property rights and develop the technology (Markman et al., 2005). While licensing agreements might still be reached, the characteristics of license agreements in the presence of embryonic inventions, and the substantial uncertainty about the value of the invention, makes payment agreements and licensing negotiations more complex and nuanced (Thrusby et al., 2001).

In addition to the embryonic nature of university inventions, scientific discoveries often involve a high degree of tacit knowledge, which is embodied in inventors, for the effective replication and commercial development of the underlying technologies. This characteristic of many scientific discoveries renders markets for technology ill-suited for ensuring successful applications. In this context, it is “people transfer” more than “technology transfer” that is required for successful commercialisation (Zucker and Darby, 1996). Therefore, when inventions derive from high impact scientific discoveries, it is particularly likely that inventors themselves will take the lead in the commercial development of technologies, through the formation of a spin-off company. This characterisation of academic entrepreneurship corresponds to a science-push perspective where entrepreneurs from research contexts (such as universities) benefit from tacit knowledge related to technological and scientific advances to devote efforts to commercially develop inventions at a ‘proof of concept’ or early phase of development (Adams et al., 2015; Clarysse et al., 2011). Thus, we put forward the following hypothesis:
Hypothesis 1b. Upstream sources of knowledge are more strongly associated with academic entrepreneurship than with technology transfer, such that: scientists who have a track record of high impact scientific contributions are more likely to engage in firm creation than technology licensing.

Downstream knowledge sources as antecedents of academic entrepreneurship and technology transfer

The influence of contact with user communities has been highlighted in the entrepreneurship literature as a critical source of knowledge to explain the capacity to identify and exploit entrepreneurial opportunities (Adams et al., 2015). Proximity to users provides a deeper understanding of unmet needs and a contextual knowledge of markets which are essential in shaping entrepreneurial behaviour (Shane, 2000). The influence of the interaction with actors belonging to close-to-market settings is also important within the academic context, and particularly relevant to examine the factors underlying entrepreneurial behaviour among scientists.

Direct contact with research beneficiaries has traditionally represented a critical source of knowledge to identify potential pathways for the commercial exploitation of findings from scientific research. For instance, interaction with industrial practitioners in the context of scientific research activities has been identified as a strong predictor of entrepreneurship and technology transfer (D'Este et al., 2012; Grandi and Grimaldi, 2005; Landry et al., 2007). This does not come as a surprise since interaction with research beneficiaries is likely to enhance the scientists’ awareness and understanding of the unmet specific demands and problems faced by non-academic actors. In line with Shane’s (2000) arguments on entrepreneurs’ idiosyncratic prior knowledge, contact with the potential beneficiaries of research is likely to provide critical insights on which markets to enter, how to serve markets, and what kind of customer problems should be addressed by new technologies.

This characterisation of the knowledge-base antecedents of academic entrepreneurship and technology transfer corresponds to a demand-pull perspective where scientists benefit from, and are triggered by, downstream knowledge related to the market context and user needs. This demand driven approach is consubstantial with the claim that ‘engaged scientists’ are particularly well-equipped to become entrepreneurs. The expression
‘engaged scientists’ refers to those academics who have a close and frequent interaction with non-academic communities in the context of their research activities, and whose research goals are often framed in conjunction with such communities (Olmos-Peñuela et al., 2015; Perkmann et al., 2013).

A high degree of academic engagement with research beneficiaries is typically epitomised by the case of scientists who are often involved in research contracts and consulting agreements, in which research goals directly respond to problems and needs raised by practitioners in non-academic contexts (Perkmann and Walsh, 2009). In short, the sources of knowledge gained in downstream - close to market - research activities is likely to have a strong impact on the scientists’ understanding of user needs and identification of the potential market opportunities entailed by their scientific discoveries. This implies that engaged scientists are likely to be well-equipped both to identify and exploit business opportunities, and to achieve research findings that respond to the needs of non-academic audiences. Thus, we put forward the following hypothesis:

**Hypothesis 2a.** Downstream sources of knowledge will have a positive effect on academic entrepreneurship and technology transfer, such that: scientists who have established direct interaction with potential beneficiaries of research are more likely to engage in firm creation and technology licensing.

The market-driven rationale underlying the downstream knowledge-base antecedents of entrepreneurship and technology transfer highlights the importance of direct interactions with research beneficiaries. These interactions have two relevant implications for the type of commercialisation route undertaken by ‘engaged scientists’: building trustful relationships and developing closer-to-market technologies.

Direct and frequent interactions with research beneficiaries contributes to align (often conflicting) norms and incentives between university scientists and industry practitioners, and mitigates problems associated with different research orientations and goals (Bruneel et al., 2010). More specifically, a track record of timely and effective delivery from previous research projects undertaken with non-academic partners helps scientists building trust with a wide range of parties involved in research projects. It also contributes to gain a reputation of being a reliable research partner among non-academic actors, regardless of whether there have been previous direct interactions with these actors. This rich social
capital might be instrumental to smooth, and potentially overcome, the information problems associated with markets for inventions when new technologies are based on highly embryonic academic inventions. While much of the university inventions are distant from market application and may require the inventor’s involvement and active cooperation for commercial success, scientists who have established trustful relationships with non-academic partners would be particularly credible to ensure that no opportunistic behaviour would unleash during the development process of early phase technologies.

Additionally, direct interactions with research beneficiaries increase the chances that scientific research may contribute to generate technologies that display a high degree of technological resolution: i.e., inventions which are at a prototype stage and/or represent technologies for which a market has been identified (Markman et al., 2005). When a new technology demonstrates a path to commercialisation and application in specific industry settings, there is a lower degree of uncertainty about the economic returns and, as a result, licensing agreements are more straightforward to achieve. Therefore, when inventions derive from strong direct interaction with research beneficiaries (i.e. downstream sources of knowledge), it is particularly likely that inventors will consider a licensing agreement as the most suitable path for commercialisation. This characterisation of technology transfer corresponds to a market-pull perspective where university scientists benefit from greater understanding of user needs and manage to develop technologies at a ‘prototype stage’ or more easily transferable and suitable for arm’s length transactions in markets for technology (Adams et al., 2015). Thus, we put forward the following hypothesis:

**Hypothesis 2b.** Downstream sources of knowledge are more strongly associated with technology transfer than with entrepreneurship, such that: scientists who have established direct interaction with potential beneficiaries of research are more likely to engage in technology licensing than firm creation.

**Interplay between upstream and downstream sources of knowledge**

The upstream-downstream divide is a useful dichotomy from a conceptual viewpoint in order to characterise two contrasting alternative antecedents of academic entrepreneurship and technology transfer. However, when examining the knowledge-background profiles of scientists who engage in firm creation and technology licensing, these two sources of knowledge represent extreme cases which may be hard to find as completely separate from each other. While upstream knowledge sources may enhance the chances of opportunity
identification, the lack of understanding of the context of application may undermine the capacity of scientists to act upon a commercial opportunity from an invention, even if it has a high market potential. Similarly, while downstream knowledge sources may enhance opportunity recognition, it may not be enough to set in motion an entrepreneurial action in the absence of a scientific contribution that significantly adds to the pool of existing technologies.

Following this reasoning, it seems critical to examine the interplay between upstream and downstream knowledge sources, since it is the combination of both upstream and downstream sources of knowledge that might fundamentally matter for entrepreneurship and technology transfer (Shane and Venkataraman, 2000). This potential reinforcing effect of upstream and downstream sources of knowledge, as an underlying antecedent of academic entrepreneurship and technology transfer, is reminiscent of the role of the ‘bridging scientist’, as suggested in the entrepreneurship and innovation literatures (Baba et al., 2009; Gittelman and Kogut, 2003). The term ‘bridging scientist’ refers to those scientists who manage to reconcile the conflicting norms and incentives prevailing in science and market environments (Sauermann and Stephan, 2013). In this sense, ‘bridging scientists’ are characterised by their capacity to recognize the potential applicability of the results of leading-edge academic research, and to undertake exploratory research inspired by the insights derived from the challenges faced by industrialists and non-academic actors (Baba et al., 2009; Subramanian et al., 2013).

In contrast to the above argument, we argue that the interplay between upstream and downstream knowledge sources is likely to work differently for the two commercialization pathways analysed in this study. We expect a complementary relationship between the two sources of knowledge in the case of firm creation, such that downstream sources of knowledge are expected to positively moderate the relationship between upstream knowledge sources and firm creation. Conversely, we expect a substitution effect in the case of technology transfer, such that downstream knowledge sources may compensate for the absence (or low presence) of upstream knowledge sources.

The discussion preceding our first and second hypotheses (i.e. Hypotheses 1a/1b) suggests that inventions stemming from high-impact scientific discoveries are comparatively more likely to be commercialised through new company formation than through licensing
agreements. However, scientists with a track record of high-impact scientific discoveries may be particularly visible and prominent in scientific networks, but might be comparatively less prominent in attracting a sufficiently diversified range of non-academic actors. This potential bias against a sufficiently heterogeneous social capital may severely limit the capacity of scientist to identify and act upon entrepreneurial opportunities. Against this background, scientists who have established strong interactions with potential beneficiaries of research would ensure a greater understanding about the market needs that the new technology should meet (Shane, 2000), and access to complementary assets such as financial support and marketing competencies to set up a company to exploit the new technology (Mosey and Wright, 2007). Thus, we put forward the following hypothesis:

**Hypothesis 3a.** Upstream and downstream sources of knowledge have a reinforcing effect on academic entrepreneurship, such that: scientists who have jointly contributed to scientific research breakthroughs and established direct interactions with research beneficiaries, are more likely to engage in firm creation.

The discussion preceding our third and fourth hypotheses (i.e. Hypotheses 2a/2b) suggests that inventions deriving from research involving direct interaction with potential research beneficiaries are comparatively more likely to be commercialised through licensing agreements than through new company formation. In this case, we expect a substitution effect between upstream and downstream knowledge sources, with regards to engagement in technology transfer: i.e. greater reliance on downstream knowledge sources more than compensates for the absence (or lower levels) of upstream sources of knowledge. The rationale underlying this claim is that greater degrees of interaction with research beneficiaries are likely to reinforce the capacity of scientists to identify commercial opportunities from research findings which did not necessarily stand out as high impact scientific contributions. In other words, it is in the context of regular (non-outstanding) research findings where direct interactions with beneficiaries may be of particular relevance to help identifying potential commercial value from scientific inventions. Additionally, greater interaction with research beneficiaries is likely to inspire research with a focus to deliver useful applications and to develop inventions with a higher degree of technological resolution, which increases the readiness of inventions for market transactions. Thus, we put forward the following hypothesis:
**Hypothesis 3b.** Upstream and downstream sources of knowledge have a substitution effect on technology transfer, such that: the detrimental effect of weak scientific performance on the likelihood of engaging in technology licensing will be more than compensated by scientists’ greater levels of direct interaction with research beneficiaries.

### 3. Data, variables and methodology

This study draws on multiple sources of data. On the one hand, primary data from a large scale survey of all tenured scientists in the Spanish National Research Council (CSIC), which is the largest public research organization in Spain. The population surveyed consisted of all scientists affiliated to CSIC who had a permanent contract, amounting to 3,165 scientists by 2010 (CSIC, 2010). These scientists were all invited to participate in an on-line survey taking place between April and May 2011. We obtained 1,295 valid responses, accounting for a 41% response rate (Table I).

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In addition to the survey data, this research collected information from three secondary sources. First, data from administrative sources provided by CSIC, which reported the number of formal agreements and volume of income associated with every R&D contract, consulting activity and licensing of IPRs in which CSIC scientists were involved as principal investigators since the late 1990s. This source also included information on socio-demographic characteristics of our population of scientists on gender, age, academic rank and institute of affiliation. Second, we collected bibliometric data from Web of Science (WoS) to obtain publication and citation profiles of CSIC scientists over their full careers. And third, we merged our dataset with information from a directory of spin-offs created (prior to 2007) in Spanish universities and public research organisations, and which were still active by 2007 (Morales-Gualdrón, 2008; Morales-Gualdrón et al., 2009).

#### 3.1. Dependent variables

To assess the extent to which scientists are involved in commercialisation behaviour, we draw upon the responses in our survey to a couple of question asking scientists to report whether they have engaged, at least once over the period 2009-2011, in the formation of a company, and whether they have engaged at least once (over the same period of time) in
technology licensing agreements. The responses to these two questions allow us to build two dichotomous variables that take value 1 if responses were confirmatory, and zero otherwise. We call these variables: Spin-offs and Licensing.

Table II shows that about 2.5% of scientists in our sample have been involved in spin-offs, while about 14% are involved in technology licensing. These figures are in line with the proportion of academic scientists involved in spin-offs activities as reported in other studies (see for instance Abreu and Grinevich, 2013; Perkmann et al., 2013). We also observe that the prevalence of academic entrepreneurship and technology transfer displays substantial differences across disciplines. The proportion of scientists involved in spin-offs is particularly high in ‘Biology and Biomedicine’ (4.3%) and ‘Physics’ (4.5%), while the highest proportion of scientists engaged in technology licensing corresponds to the scientific fields of Food Science & Technology (26.6%) and Materials Science & Technology (20.4%). It is interesting to note that the two scientific fields with a higher proportion of scientists engaged in firm creation correspond to areas of research typically associated with basic science, while the two scientific fields with a higher proportion of scientists engaged in technology licensing correspond to areas of research associated with more applied or engineering-based sciences.

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3.2. Independent variables
This sub-section describes our two independent variables: upstream sources of knowledge and downstream sources of knowledge.

Upstream sources of knowledge
Upstream knowledge is measured by the extent to which scientists have contributed to major scientific advances and breakthrough discoveries. We capture these outstanding scientific contributions by the number of articles published by a scientist which are among the top 10% most cited in their corresponding scientific field and publication year. We have built this measure by considering all the articles and reviews published by each researcher, as recorded in the Web of Science (WoS), during the 5-year period 2004-2008.
The choice of this time frame is deliberate, in order to avoid a temporal overlap with the time frame used in the survey to build our dependent variable (i.e. 2009-2011). To assess the scientific impact of each article, we have used a citation window of three years to capture the count of citations received by each article, considering the year when the paper was published plus two additional years. On the basis of these records, we have identified articles among the top 10% most cited (compared to papers published in same year and scientific field). This measure, which is labelled Upstream_knowledge_sources, provides information on the number of major scientific contributions of our sample of scientists.

Despite of the limitations of using citations as an indicator of impact of scientific research (as pointed out by Martin and Irvine, 1983; and Nicolaisen, 2007, among others), measures based on citation counts are frequently used as a proxy of scientific impact. Moreover, in recent years there has been an especial emphasis on indicators reflecting the top of the citation distribution (i.e. the top 10% most cited publications), under the assumption that they reflect better the most outstanding contributions to science and “research excellence” (Bornmann, 2014). The measure we use in this study aligns to this approach and meets the standards proposed by Waltman et al. (2011) for the construction of robust and reliable bibliometric-based indicators of scientific impact.

Downstream sources of knowledge

Downstream knowledge is measured by the extent to which scientists have established direct interactions with the potential beneficiaries of their research activities. We capture these interactions by using information from research contracts and consulting agreements established by scientists with non-academic actors. These agreements are characterised by interactions mediated through formal contracts, where academic scientists respond to specific needs and demands from potential beneficiaries, typically by carrying out an assignment or a short-term research involving a well-defined goal set by the non-academic party - who is usually the funder of these targeted research agreements.

We build this measure by considering the total volume of income from R&D contracts and consultancy activities in which scientists have been involved as principal investigators, over the 5-year period 2004-2008 (keeping the same time-frame used for our measure of upstream sources of knowledge). We use information on income-streams associated with contracts in order to weight for the varying degree of strength of interactions with
stakeholders. These R&D contracts and consulting involve formal agreements with a wide range of non-academic actors, including: businesses, public administration, hospitals, non-profit organisations and NGOs, among others. Secondary data to build this measure comes from administrative information provided by the CSIC, and represent a comprehensive and reliable data on formal interactions with non-academic actors, since CSIC scientists are legally required to accurately report to CSIC central offices about every source of income associated with research activities. This measure, labelled ownstream_knowledge_sources, provides information on the degree of interaction with potential beneficiaries of research by our sample of scientists.

For the purpose of the analysis and the descriptive statistics, we have transformed both explanatory variables by taking natural logarithms, given the extremely asymmetric distribution of these two variables. Additionally, these variables have been standardised to examine interaction effects.

3.3. Control variables
We have considered a number of control variables to avoid biased results. First, we accounted for the individual propensity to engage in commercialisation activities. To do this, we have built two variables. The first one measures the extent to which scientists have been involved, over the period 1999-2010, in the licensing of patenting or any other IPRs. More specifically, we measure the total volume of income associated with licensing activities in which our sample of scientists have been involved. This measure allows us to identify scientists who have been frequently involved in commercialisation activities, what we called: habitual commercialisers. The total volume of income generated through licensing was log transformed for the analysis. This data also comes from sources provided by CSIC. The second variable captures the extent to which our sample of scientists has been involved in the formation of spin-off companies prior to the period reported in our survey, and it is measured as a dichotomous variable that takes value 1 if scientists were involved in firm creation (and 0 otherwise). We matched the names of scientists in our sample with the names of academic inventors from a directory of all spin-offs created prior to 2007 in Spanish universities and public research organisations, as reported in Morales-Gualdrón (2008). This measure allows us to identify scientists who have been involved in entrepreneurial activities previous to the reporting period from our survey. We labelled this variable: past entrepreneurial experience.
We also included variables related to the motivation of scientists towards research activities. Motivational aspects are likely to play an important role in shaping the attitude of scientists with regards to engagement in entrepreneurial behaviour and interactions with industry (D’Este and Perkmann, 2011; Lam, 2011). We therefore control for a number of motivational features based on self-determination theory (Deci and Ryan, 2000). We consider two general types of motivations regarding the main drivers of scientists’ engagement in research activities: autonomous motivation and controlled motivation. To build these two motivational variables we draw on a question in the survey asking about the importance attached to a list of items (using a 4 point Likert scale, ranging from ‘no importance’ to ‘extremely important’) regarding “your job as a researcher”. The three items considered to build the autonomous motivation scale included: ‘to face intellectual challenges’; ‘to have greater independence in your research activities’; and ‘to contribute to the advance of knowledge in your scientific field’. While the three items included in the controlled motivation scale were: ‘salary’; ‘job security’; and ‘career advancement’. We computed the average response to these three items (the corresponding Cronbach alpha coefficients were 0.65 and 0.71, respectively).

Regarding demographic characteristics, we control for the age, gender (male) and academic status (taking the value 1 for the category of professor). To control for features associated to scientific productivity, we include the following variable: number of articles published in the last five years (transformed into logarithms). Professional experience is captured through previous experience in the private sector, as measured by the number of years employed in the private sector. Finally, to account for the specificities of the type of research conducted by scientists, we control for a variable that captures the scientists’ research orientation by measuring whether scientists are inspired by the application of their research (Stokes, 1997). This measure (Applied-Focus) comes from responses in the survey to the following single-item question: ‘to what extent is your research inspired by the practical use and applications outside the scientific environment’ (framed as a 4-point Likert scale, ranging from ‘not at all’ to ‘very much’).

We also control for the degree to which the academic organisational environment provides high or low levels of support for commercialisation activities (Organisational_support). We draw on data from the survey. In particular, we examine responses to a specific section
of the questionnaire where respondents were asked to report whether they have used the services provided by their research institutes or departments to support commercialisation activities. More precisely, the questionnaire asked about the use of any of the following six services oriented to provide assistance on: a) searching for contacts to find non-academic partners; b) getting information about the ways to establish partnerships with non-academic actors; c) supporting the negotiation of contracts; d) getting information about available public funds to collaborate with other entities; e) getting information about intellectual properties; and f) administrative management of contracts. Drawing on these responses, we have built an indicator following a method similar to the one suggested by Bozeman and Gaughan (2007), constructing an organizational support index as a weighted sum of the services used by a scientist, where the weights correspond to the frequency of use of each service, among the whole sample of scientists in our study.

Finally, we included a set of dummy variables indicating the eight research areas within CSIC (listed in Tables I and II). Tables III and IV provide information on the descriptive statistics for all the variables included in our analysis, and the associated correlation matrix.

<table>
<thead>
<tr>
<th>Table III</th>
<th>Table IV</th>
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</table>

Due to the dichotomous nature of the dependent variable, and the fact that the two events being examined (firm creation and licensing) are not independent from each other (see Table IV), we conduct a multivariate probit regression model to examine how different knowledge sources (upstream and downstream) affect the probability of undertaking entrepreneurial and technology transfer activities. The advantage of this method is that it allows for systematic co-variances between the two dependent variables examined in this study (Capellari and Jenkins, 2003).

4. Results

4.1. Heterogeneity of scientists’ profiles according to type of knowledge sources

Our results contribute to highlight the extent to which scientists differ in terms of their reliance on upstream and downstream sources of knowledge. To illustrate this, we have
plotted our complete sample of scientists along two axes, reflecting the extent to which scientists draw upon upstream and downstream knowledge sources (see Figure 1). The red lines, which divide the figure in four quadrants, indicate the value that corresponds to the top quartile of each distribution. While the dashed lines highlight those scientists who have a score of zero for either upstream or downstream knowledge sources.

Figure 1 suggests a wide range of profiles among scientists. It is worth noting that a substantial proportion of cases have zero scores on either upstream or downstream sources of knowledge. More precisely, about 65% of scientists had either no income from formal R&D contracts and consulting or no papers among the top 10% most cited (with 18% of cases having zero scores on both measures); while 35% of our cases are scattered around the four quadrants with positive (above zero) scores on both dimensions (upstream and downstream knowledge sources). The vertical dashed line highlights scientists who have had no formal interaction with research beneficiaries, but display a huge variety in terms of the scientific impact of their publications. While the horizontal dashed line includes those academic scientists who have had no outstanding scientific contribution, but instead have engaged in direct interactions with non-academic beneficiaries in varying degrees.

About 8% of the surveyed scientists are located in the top quartile on both upstream and downstream knowledge sources (top-right quadrant), while 17% of our sample stand out in capturing income from contracts and consulting (bottom-right quadrant), and another 17% of them are noticeable for having an above average number of top cited publications (top-left quadrant). We find that the proportion of scientists who engage in firm creation and licensing is highest among scientists who are located in the bottom-right quadrant: 6.3% of scientists in this quadrant have engaged in firm creation, and 24% have engaged in licensing. The second-highest figures correspond to the top-right quadrant, with 4% of scientists engaged in firm creation and 22% in licensing. While scientists located in the top-left quadrant come next: 2.4% and 13.6%, respectively. These proportions are lowest for scientists in the bottom-left quadrant: 1.1% and 10.4%, respectively.
In sum, Figure 1 contributes to highlight that there is a wide heterogeneity of profiles among scientists who engage in commercialisation activities, with regards to the sources of knowledge they draw upon. This suggests the co-existence of alternative knowledge-based profiles as antecedents of scientists’ engagement in firm creation and technology transfer. The next section provides a systematic examination of the extent to which there is a significant relationship between the reliance of scientists on upstream and downstream knowledge sources, and their engagement in firm creation and technology licensing.

4.2. Statistical analysis and econometric results

In Table V we report the results for the multivariate probit analysis, examining the relationship between knowledge-based antecedents and academic commercialisation activities (i.e. firm creation and licensing). In columns 1a-1b we report results for firm creation (1a) and licensing (1b) including only the control variables. As expected, having been frequently involved in technology licensing activities in previous years (i.e. being a habitual commercialiser) and past involvement in firm creation (i.e. having past entrepreneurial experience) are positively and strongly associated with spin-off creation and with current licensing. Also, the applied orientation of research (Applied_Focus) is significantly associated with both firm commercialisation activities. While gender (i.e. male) and organisational support are significantly associated with licensing but not with firm creation.

Columns (2a-2b) report the results when we include ‘upstream knowledge sources’ as predictor, showing that upstream sources of knowledge have a significant association with spin-off formation, but a weakly significant (and negative) association with technology licensing. Columns (3a-3b) show the results for the estimated coefficient of ‘downstream knowledge sources’, which is strongly positive and significantly associated with both firm creation and licensing. Finally, columns (4a-4b) provides results when including both upstream and downstream predictors simultaneously: we find that while upstream knowledge sources are only positively associated with firm creation, downstream knowledge sources are positively associated with both firm creation and licensing. Overall, these results provide strong support for hypothesis H1b, suggesting that upstream knowledge sources are particularly associated with firm creation, compared to licensing; and only provide partial support for hypothesis H1a, as we find that upstream knowledge sources are only positively and significantly associated with firm creation, but they do not
act as strong antecedents for both commercialisation paths. Indeed, there is evidence (though weakly significant) of a negative association between upstream knowledge sources and licensing. The results also strongly support hypothesis H2a, indicating that downstream knowledge sources are positively associated with both commercialisation paths. However, our results lead us to reject hypothesis H2b since we do not find evidence supporting that the effect of downstream knowledge sources is stronger for licensing than firm creation (i.e. estimated coefficients are not significantly different).

Finally, columns 5a-5b include the interaction term between upstream and knowledge sources. The results show that the interaction term is positive but not statistically significant for firm creation, while it is negative and statistically significant in the case of licensing. The non-significance of the multiplicative term for firm creation suggests that scientists who draw upon both upstream and downstream sources have neither greater nor lower likelihood of engaging in spin-off creation, compared to scientists who are mainly drawing on either upstream or downstream sources, independently. While this result does not support H3a, disconfirming the presence of a reinforcing effect between upstream and downstream, we do not find any suggestion of a detrimental effect either. In this sense, this result points out that the joint occurrence of upstream and downstream is at least as conducive to spin-offs as the pathways of drawing upon either upstream or downstream sources, separately. Regarding technology licensing, our results provide strong support for hypothesis H3b, suggesting the presence of a substitution effect between upstream and downstream sources of knowledge. In this sense, these results point out that the positive effect of downstream knowledge sources on licensing is particularly strong for scientists who display a comparatively lower scientific performance.

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INSERT TABLE V ABOUT HERE
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Overall, these results suggest that upstream and downstream sources provide alternative paths for academic entrepreneurship (firm creation). In fact, we find no significant differences between the estimated coefficients of upstream and downstream knowledge sources, from results reported in column 4a. This means that both knowledge sources can be considered as similarly strong antecedents of academic entrepreneurship. This contrasts
with our findings regarding licensing (column 4b), where it is mainly downstream knowledge sources which are largely conducive to this type of commercialisation behaviour, as compared to the weakly negative effect of upstream knowledge sources.

Moreover, the strong effect of downstream knowledge sources is further reinforced by its capacity to moderate the relationship between upstream knowledge sources and licensing. Figure 2 provides a visual representation of the negative interplay between upstream and downstream knowledge sources on the probability of engaging in technology licensing. The figure shows that relationship between upstream knowledge sources and engagement in licensing is positive for scientists with low scores of downstream knowledge sources; while the relationship is negative for scientists who exhibit higher scores of downstream knowledge sources.

5. Discussion and Conclusions
This research investigates alternative knowledge-base antecedents of academic entrepreneurship and technology transfer. We advance existing research by contributing to identify the knowledge sources which are conducive to scientists’ involvement in commercialisation activities - i.e. mainly, upstream and downstream knowledge sources. And second, by highlighting that these two knowledge-base antecedents have distinct roles as explanatory factors to explain the two types of commercialisation activities examined in this study: firm creation and licensing. Below we discuss some theoretical and managerial implications of our findings. Additionally, we consider some limitations of the study and potential directions for future research.

Theoretical implications
Scholarship in entrepreneurship has advanced our understanding on how information asymmetries and differences in prior knowledge influence the individual capacity to identify and exploit entrepreneurial opportunities (Shane, 2000). Our study advances this stream of research by extending the conceptual framework to the academic
entrepreneurship and university-business interaction literatures, and by examining the effects of two contrasting sources of information and knowledge that emerge from scientists’ research activities: upstream and downstream knowledge sources. We find strong empirical support for the propositions that both upstream and downstream sources of knowledge are strongly associated with academic entrepreneurship and technology transfer, though their influence is rather different for each type of commercialisation path.

More specifically, our study shows that upstream knowledge sources, which refer to idiosyncratic information and knowledge gained through outstanding contributions to technological advances and breakthrough discoveries, represent a key antecedent of entrepreneurial action among academics, but they have a much lower significance (if any) as a predictor of engagement in licensing activities. In fact, we find evidence that technology licensing is more strongly associated with research of ordinary scientific impact than with outstanding scientific contributions. On the other hand, our results show that downstream knowledge sources, which refer to distinctive information and knowledge on markets and user needs gained through direct interaction with research beneficiaries, represent a critical antecedent of both entrepreneurial and technology transfer behaviour. Moreover, we find that both upstream and downstream knowledge sources display a similar degree of association with entrepreneurial behaviour, and there is no evidence of a reinforcing effect when scientists exhibit exposure to both sources of knowledge jointly - meaning that scientists who draw on both sources of knowledge simultaneously do not exhibit either a greater or a lower probability of becoming an entrepreneur compared to scientists who mainly draw on upstream or downstream sources separately.

These results point out a number of important implications. First, our findings challenge the implicit assumption of a science and technology push model as the dominant paradigm of entrepreneurship within the academic context. Whereas the focus on technological and scientific contributions as the main drivers of academic entrepreneurship has received extensive attention in the literature, we show that downstream knowledge from direct interaction with research users and beneficiaries bears a comparable effect in terms of shaping entrepreneurial action among academics. Our findings therefore suggest that research on academic entrepreneurship should adopt a more balanced approach to knowledge-based antecedents of entrepreneurship, by considering both upstream and
downstream sources of knowledge as equally relevant factors in shaping the entrepreneurial behaviour of academic scientists.

Second, our results provide support for the existence of three alternative pathways to academic entrepreneurship, according to the type of knowledge sources gained by scientists in the course of their research activities. The first one would correspond with the idea of ‘star scientists’, being exemplified by scientists who exhibit outstanding contributions to science as the knowledge-based antecedent to frame entrepreneurial opportunities, despite of an absence or low degree of interaction with potential research beneficiaries. The second pathway aligns with the emergence of ‘engaged scientists’, fundamentally represented by scientists who identify and act upon entrepreneurial opportunities as a result of their active involvement in interactions with research beneficiaries, user communities and other non-academic stakeholders (regardless of whether their track record of scientific contributions is outstanding or not). And a third pathway, which is characterised by the role of ‘bridging scientists’, as scientists who engage in entrepreneurial action by drawing upon both upstream and downstream knowledge sources simultaneously, exhibiting a pattern of outstanding contributions to science and a direct, frequent interaction with research beneficiaries. These three archetypes of academic entrepreneurs - ‘star scientists’, ‘engaged scientists’, and ‘bridging scientists’ - highlight the heterogeneity of knowledge-based antecedents of entrepreneurial behaviour within the scientific community. These results advance existing research on the role of a knowledge context approach on academic entrepreneurship (Agarwal and Shah, 2014), by expanding our understanding of how differential knowledge sources shape individuals’ decisions to engage in firm creation.

Finally, our results point out that the two main routes of commercialisation of inventions from scientific research are driven by distinct sets of knowledge-base antecedents. For inventions commercialised via licensing agreements, the critical source of knowledge originates from greater technology and market understanding gained through direct interaction with beneficiaries, not from knowledge gained through high-impact scientific discoveries. Indeed, our results strongly indicate that interaction with beneficiaries help realise the market potential and business opportunities associated with findings from regular science, as opposed to discoveries from outstanding research. Overall, this suggests contrasting profiles of knowledge-base antecedents for technology transfer (licensing) and
entrepreneurship (firm creation). The archetype of scientists engaged in technology transfer seem to correspond with the profile of the ‘engaged scientist’ - scientists who are highly involved in direct interaction with research beneficiaries, regardless of their track record in terms of scientific achievements. Our results further confirm this profile by pointing out that downstream knowledge sources are by far the stronger knowledge-base antecedent of technology transfer (while upstream sources playing a weakly negative influence as predictors), and by confirming a substitution effect between upstream and downstream sources on licensing activities, which suggests that downstream knowledge sources compensates for the lack of upstream knowledge sources in shaping technology transfer behaviour.

Managerial implications
This study provides insights for managers and policy-makers. As argued above, our results provide empirical evidence in support for the co-occurrence of differentiated pathways to academic entrepreneurship - star scientists, engaged scientists and bridging scientists. Therefore, universities and public research organisations oriented to foster academic entrepreneurship may follow highly diversified policies and strategies. Incentive structures and support mechanisms for promoting academic spin-offs formation may be oriented to stimulate multiple combinations of upstream and downstream knowledge sourcing among scientists, since both breakthrough academic discoveries and R&D contracts and consulting activities may contribute, either separately or jointly, to enhance the identification and exploitation capacities needed for entrepreneurial action.

Moreover, our results highlight that research that involves strong interaction with non-academic actors and research beneficiaries enhance identification of business opportunities from research findings that otherwise might remain unrealised, and the capacity to exploit business opportunities through the development of technologies at prototype stage or higher degrees of technical resolution, which are more suitable for market for inventions. In this sense, university policies oriented to strengthening direct interaction with research beneficiaries may contribute to favour the realisation of the economic returns of the available pool of inventions and technologies from scientific research, including both breakthrough discoveries and inventions accounting for more incremental technological contributions.
Connected to the previous point, research policies at the country level should take into account that evaluation systems fundamentally oriented to the measurement and reward of scientific excellence may be partially self-defeating with regards to the objective of achieving societal impact. Research policies should find an adequate balance between contrasting incentive schemes, encouraging the pursuit of diverse research portfolios, opening up opportunities to draw on both upstream and downstream sources of knowledge.

Finally, whereas recent studies have suggested that only a minority of researchers are aware of the actual functions provided by TTOs at their universities (Huyghe et al., 2016), we show a prevalent positive influence of the immediate organisational setting, at the department or research institute level, where scientists perform their daily research activities. Closer supportive organisational contexts seem to be particularly effective to facilitate knowledge and technology transfer activities. Responding to the call from Siegel and Wright (2015, p. 592) - “research is needed on the benefits and challenges in incentivizing academics to move to more favourable ecosystems for academic entrepreneurship” - this study points out that institutional supportive programmes need to accommodate the existing heterogeneity of academic entrepreneurship paths displayed within the scientific community. In that sense, we find a strong association between the organisational support services at department levels (e.g. identifying external contacts, providing management support, or offering information on legal procedures, funding opportunities or IPR) and the degree of engagement of scientists in technology licensing activities.

Limitations and future research

Although the empirical setting for our study provides unique information on a large and representative sample of scientists from the largest public research organisation in Spain (i.e. National Council for Scientific Research), we need to be cautious about the generalizability of our findings. While we propose that similar patterns are likely to be identified in other academic settings and across different time windows, future research should test the robustness of our findings. Like most studies based on survey research, there is potential for endogeneity and reverse causality in our research design, and therefore we have been cautious about making claims supporting causal relationships. However, it is worth noting two attributes of the research design that partially attenuate problems associated with reverse causality. First, we have built our key independent
variables - upstream and downstream knowledge sources - from secondary sources and covering time periods that precede that of our dependent variable. And second, we have taken account of individual-level covariates which control for important differences in individuals’ propensity to engage in both entrepreneurial and technology transfer activities, thus controlling for alternative explanatory factors of the scientists’ examined behaviour and for past engagement in licensing and entrepreneurial activities.

Another limitation in our current empirical setting refers to the absence of further information on the performance of the spin-offs created. Subsequent studies should address the extent of failure or success of the spin-offs ventures in order to advance our understanding of academic entrepreneurship dynamics. Research on performance would contribute to identify potential links between knowledge sources associated with firm creation and the type of spin-off created, in terms of choice of markets, growth and survival. Finally, our findings on three distinctive knowledge-based antecedents of entrepreneurial behaviour open a new fruitful avenue for further research. Particularly, more qualitative approaches, should contribute to enhance our understanding on the processes that lead to entrepreneurship among these different types of scientists, and provide greater guidance to foster selective supportive policy orientations.
References


Lam, A. (2011) 'What motivates academic scientists to engage in research commercialization:'Gold’,'ribbon'or ‘puzzle’?'. *Research Policy, 40* (10), 1354-1368.


Nicolaisen, J. (2007) 'Citation analysis.' *Annual review of information science and technology*, 41 (1), 609-641.


Tables and Figures

<table>
<thead>
<tr>
<th>Scientific field</th>
<th>Surveyed population</th>
<th>Valid responses</th>
<th>Response rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural Sciences</td>
<td>362</td>
<td>191</td>
<td>53%*</td>
</tr>
<tr>
<td>Biology &amp; Biomedicine</td>
<td>537</td>
<td>199</td>
<td>37%</td>
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<tr>
<td>Chemistry Science &amp; Technology</td>
<td>378</td>
<td>179</td>
<td>47%*</td>
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<td>Food Science &amp; Technology</td>
<td>242</td>
<td>119</td>
<td>49%*</td>
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<td>Materials Science &amp; Technology</td>
<td>427</td>
<td>164</td>
<td>38%</td>
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<tr>
<td>Natural Resources</td>
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<td>190</td>
<td>40%</td>
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<tr>
<td>Physical Science &amp; Technology</td>
<td>418</td>
<td>163</td>
<td>39%</td>
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<tr>
<td>Social Sciences &amp; Humanities</td>
<td>318</td>
<td>90</td>
<td>28%*</td>
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<td><strong>Total</strong></td>
<td><strong>3,165</strong></td>
<td><strong>1,295</strong></td>
<td><strong>41%</strong></td>
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</tbody>
</table>

* They significantly differ (chi-square p < 0.05) when compared to the overall response rate of the other fields in our sample. Information about surveyed population comes from CSIC Annual Report (CSIC, 2010).
<table>
<thead>
<tr>
<th>Scientific field</th>
<th>Spin-offs</th>
<th>Licensing</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural Sciences</td>
<td>1.6</td>
<td>14.2</td>
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<td>Biology and Biomedicine</td>
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<td>Natural resources</td>
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<tr>
<td>Total</td>
<td>2.5</td>
<td>14.3</td>
<td>1,220</td>
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</table>

Note: While the total number of respondents is 1,295, we report figures on academic entrepreneurship (i.e. spin-offs) and technology transfer (i.e. licensing) for the restricted sample of 1,220 researchers, corresponding to the number of cases for which we have complete data (no missing values) for all the relevant variables used in this study.
Table III. Descriptive statistics

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<th>Name</th>
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<th>Stand. Dev.</th>
<th>Min.</th>
<th>Max.</th>
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<td>Licensing</td>
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<td>Downstream knowledge_sources*</td>
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<td>Habitual commercialisers*</td>
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<td>Autonomous Motivation</td>
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* The figures for these variables display the raw values rather than the transformed ones that we use in the econometric analysis.
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* p < 0.05
| Table V. Results of Multivariate probit regressions: Dependent variables: probability of engaging in spin-offs and licensing (N = 1220) |
|---------------------------------------------------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| | (1a) | (2a) | (3a) | (4a) | (5a) | (1b) | (2b) | (3b) | (4b) | (5b) |
| Upstream knowledge sources | 0.290** | 0.299** | 0.261* | -0.104* | -0.103* | -0.070 |
| [0.115] | [0.116] | [0.134] | [0.059] | [0.059] | [0.060] |
| Downstream knowledge sources | 0.230** | 0.243** | 0.248** | 0.205*** | 0.206*** | 0.210*** |
| [0.108] | [0.110] | [0.111] | [0.056] | [0.056] | [0.056] |
| Upstream * Downstream | 0.042 | -0.106** | [0.102] | [0.042] |
| Habitual commercialisers | 0.127*** | 0.140*** | 0.117** | 0.129*** | 0.132*** | 0.080** | 0.079** | 0.071* | 0.070* | 0.069* |
| [0.042] | [0.042] | [0.043] | [0.043] | [0.043] | [0.037] | [0.037] | [0.037] | [0.037] |
| Past entrepreneurial experience | 1.495*** | 1.514*** | 1.399*** | 1.412*** | 1.395*** | 0.895** | 0.889** | 0.799** | 0.791** | 0.802** |
| [0.376] | [0.381] | [0.378] | [0.282] | [0.385] | [0.358] | [0.357] | [0.358] | [0.357] | [0.354] |
| Applied Focus | 0.251** | 0.236** | 0.200* | 0.179 | 0.183 | 0.332*** | 0.339*** | 0.288*** | 0.297*** | 0.303*** |
| [0.115] | [0.116] | [0.119] | [0.121] | [0.121] | [0.065] | [0.065] | [0.066] | [0.067] | [0.067] |
| Experience Private Sector | -0.016 | -0.009 | -0.014 | -0.007 | -0.007 | 0.001 | -0.001 | 0.002 | 0.001 | 0.001 |
| [0.040] | [0.038] | [0.040] | [0.037] | [0.038] | [0.018] | [0.018] | [0.018] | [0.018] | [0.018] |
| Controlled Motivation | -0.085 | -0.068 | -0.087 | -0.066 | -0.065 | 0.017 | 0.021 | 0.019 | 0.024 | 0.024 |
| [0.130] | [0.133] | [0.133] | [0.135] | [0.134] | [0.072] | [0.073] | [0.073] | [0.073] | [0.074] |
| Autonomous Motivation | -0.051 | -0.043 | -0.032 | -0.021 | -0.031 | 0.027 | 0.015 | 0.037 | 0.023 | 0.028 |
| [0.201] | [0.207] | [0.206] | [0.211] | [0.211] | [0.109] | [0.109] | [0.110] | [0.109] | [0.109] |
| Age | 0.009 | 0.014 | 0.004 | 0.009 | 0.008 | -0.003 | -0.005 | -0.008 | -0.009 | -0.009 |
| [0.012] | [0.012] | [0.012] | [0.013] | [0.013] | [0.007] | [0.007] | [0.007] | [0.007] | [0.007] |
| Gender (male) | 0.246 | 0.312 | 0.224 | 0.282 | 0.255 | 0.218** | 0.218** | 0.210** | 0.209* | 0.225** |
| [0.225] | [0.236] | [0.228] | [0.238] | [0.238] | [0.108] | [0.108] | [0.109] | [0.109] | [0.110] |
| Academic rank (professor) | 0.193 | 0.091 | 0.198 | 0.089 | 0.088 | 0.052 | 0.085 | 0.044 | 0.076 | 0.087 |
| [0.224] | [0.230] | [0.225] | [0.231] | [0.231] | [0.134] | [0.135] | [0.134] | [0.136] | [0.136] |
| Articles (ln) | -0.122 | -0.273* | -0.149 | -0.308*** | -0.302** | 0.113** | 0.169** | 0.089 | 0.146** | 0.148** |
| [0.094] | [0.115] | [0.096] | [0.117] | [0.117] | [0.057] | [0.065] | [0.057] | [0.066] | [0.067] |
| Organisational support | 0.105 | 0.122 | 0.083 | 0.103 | 0.101 | 0.202*** | 0.203*** | 0.183*** | 0.184*** | 0.186*** |
| [0.071] | [0.072] | [0.073] | [0.073] | [0.073] | [0.041] | [0.041] | [0.042] | [0.042] | [0.042] |
| Disciplines (dummy) | Included | Included | Included | Included | Included | Included | Included | Included | Included | Included |
| Log-Likelihood | -520.2 *** | -514.2 *** | -512.3 *** | -506.3 *** | -503.6 *** | -520.2 *** | -514.2 *** | -512.3 *** | -506.3 *** | -503.6 *** |

*p < 0.10; ** p < 0.05; *** p < 0.01
Figure 1. Distribution of scientists according to levels of Upstream and Downstream knowledge sources

Star scientist
Spin-offs: 2.4%
Licenses: 13.6%

Bridging scientist
Spin-offs: 4%
Licenses: 22%

Engaged scientist
Spin-offs: 6.3
Licenses: 24%
Figure 2. Interaction effect between Upstream and Downstream knowledge sources on technology transfer (i.e. licensing)