R versus D, from knowledge creation to value appropriation: Ownership of patents filed by European biotechnology founders

Abstract

Biotechnology firms are often created on the premise of commercialising the results of research carried out by scientists with heterogeneous careers and research trajectories. Patents filed by company founders provide accessible information on the appropriation of knowledge through the assignment of intellectual property rights (IPR).

In this study, we developed a new database of patents and publications by the founders of European, drug-originating biotech companies that reached IPO between 2013 and 2018. The founders' scientific human capital was analysed. We also developed a regression model to estimate whether the founders' career trajectories, previous publications and patent characteristics explain the appropriation of knowledge by biotech start-ups.

Our findings suggest that founders' scientific human capital and professional experience influence the way in which knowledge is captured for economic use. Compared to patents filed by industrial inventors, those filed by academics and mixed career scientists are more likely to be assigned to an inventor's own start-up company than owned by a scientist's employers. These findings lead to fundamental questions about biopharmaceutical innovation regarding issues such as whether risks and returns are appropriately shared between actors in the public and private sectors.

Keywords: patent ownership; scientific founders; knowledge technology transfer; European biotechnology

JEL classification codes: L38, L33, O31, O32, O34

1 Introduction

Biotechnology companies act as intermediaries between university-originated scientific outputs and firms with in-house commercialisation capabilities (Barley et al., 1992; Robinson and Stuart, 2007; Rothaermel, 2002; Rothaermel and Deeds, 2004; Stuart et al., 2007). Often started by academics who maintain dual appointments in both academia and industry, most biotech firms have no products at the time of their founding (Cattaneo et al., 2019; Perkmann et al., 2013). Using intellectual property titles, firms therefore seek to appropriate the value of inventions with the potential to be developed into commercially valuable products (Cohen et al., 2000; Levin et al., 1987; Maine and Thomas, 2017; Veer and Jell, 2012). Ownership of patents is especially important for newly created knowledge-intensive companies which strive to secure capital investments. Previous empirical studies have shown that the development of patents portfolios by knowledge intensive firms increases the likelihood of venture capital investments, as well as the ability to reach IPO more quickly (Audretsch et al., 2012; Baum and Silverman, 2004; Stuart et al., 1999; Haussler et al., 2009; Hoenen et al., 2014). Moreover, timely publications are used as a means to create prior art and prevent others from related patent applications while facilitating alliance formation and conveying credibility to investors (Della Malva and Hussinger, 2012; Maine and Thomas, 2017).

Most studies in the knowledge-transfer literature have thus far focused on patents and publications made by faculty inventors and academic entrepreneurs (Czarnitzki et al., 2012; Lissoni and Montobbio, 2015; Sterzi, 2013; Thursby et al., 2009). Increasing scholarly attention followed the passage of the Bayh-Dole act in 1980 in the United States, which granted universities the right to patent and licence federally funded inventions (Sampat et al., 2003; Mowery et al., 2001). Consequently, university patenting started being used as a means to explore the ‘third mission’ of universities in transferring and commercialising knowledge to industry (Leydesdorff and Etzkowitz, 1996, 1998; Etzkowitz and Leydesdorff, 2000). In Europe, legislators have been more reluctant to adopt regulations similar to those of the US. Although this has recently started to change, academics are allowed to retain ownership over the results of their inventions, in the name of so-called 'professor privilege’ (Von Proff et al., 2012). As a result, academic patents in Europe are much less likely to be owned by universities than in the United States and significant research interest has been devoted to comparing these patent regulatory environments (Mowery et al., 2001, 2002, 2015; Lissoni 2012).

Patents and publications by the founding scientists of biotech companies can be of particular importance in probing collaboration patterns, interdisciplinary linkages and other research spillovers characterising the early life of biotechnology ventures (Wang et al. 2012; Lissoni, 2012; Meyer, 2000). By centring on biotech scientific founders, the use of bibliographic and bibliometric information has the potential to highlight how knowledge is created and appropriated through the assignation of intellectual property rights.

Despite being both embedded in the scientific community, the relation between scientific founders and biotech start-ups has been a neglected focus by prior patent analyses (Thomas et al., 2020).

The aim of this study is thus to investigate patent assignment in order to explain how scientific founders of European biotechnology companies transfer their created knowledge to their own start-up. Specifically, we are interested in investigating the means by which scientific founders’ scientific and professional profiles affect the assignation of intellectual property rights to the biotech companies they start.

Our sample is drawn from 55 biotech companies headquartered in Europe that reached IPO between 2013 and 2018, from which we identify 80 scientific founders who invented 932 patents and produced 10,711 publications. We analyse these scientists' human capital based on publication and patent propensities, as well as career trajectories as derived from IPO prospectuses. Then, we develop a regression model to explain the likelihood of patent assignment to the biotech start-up.

Our main regression is a multinomial logit model in which patent assignment can take one of five forms: (1) assignment to the firm founded by the inventor; (2) assignment to the inventor's employer; (3) assignment to another firm; (4) multiple assignees; or (5) no assignment. The scientists' career trajectories are used to test whether different professional backgrounds increase the likelihood of a particular type of patent ownership model. Publication records are collected, and measures of previous research efforts are produced. Inventor experience is also considered by including the number of previous patent applications. Moreover, we rely on patent characteristics, including references to the non-patent literature, to estimate the quality and innovativeness of the knowledge disclosed.

The works closest to ours are Czarnitzki et al. (2009), Thursby et al. (2009), and Czarnitzki et al. (2012), all of which performed empirical analyses on patents held by faculty in the US and Germany. We add to these works in three ways: First, we focus on biotech founders and not simply on academic patent inventors. In doing so, we show that patent data, when not restricted to university members, provide a more comprehensive picture of the channels through which knowledge flows to the business sector (Fabiano et al., 2020a). Second, this approach explains the private ownership model of academic patents, which is prevalent in Europe. In fact, our results show that of the patents owned by for-profit organisations (64.5%), 77.8% are assigned to companies started by an academic inventor. Third, based on the results of our multinomial regression, we show that founders with experience in the industry are more likely than academics to assign patent rights to their employer than to the companies that they start.

Based on these results, we discuss the extent to which the institutional frameworks in Europe incentivise academic scientists to bypass formal university channels and take their discoveries directly to the marketplace. While showing that value creation occurs as a result of collective investment in knowledge creation, we highlight specific directions taken by knowledge embedded in individuals in the move towards the commercial arena. Understanding such directionality as a dimension of value can guide future researchers to investigate the efficiency of appropriate compensation schemes and inspire policymakers to establish more symbiotic interactions between public and private sectors.

The remainder of the paper is structured as follows. Section 2 illustrates the theoretical background summarising the previous literature on scientific founders and patent ownership. Based on the gap in the extant literature, we present our main research question and the specific objectives guiding our study. In Section 3, we present the methodological aspects in relation to the sample creation, and our descriptive analysis. Section 4 present the main results, Section 5 the econometric model, and Section 6 the discussion.

2. Conceptual framework and objectives

2.1 Scientific founders, the interface between science and commerce

In the analysis of pharmaceutical innovation, biotechnology firms are conceived as repositories of knowledge which is then channelled into the development of viable products (Gittelman and Kogut, 2003). Companies are formed with an interest in capturing knowledge produced by universities, and based on the commercial potential of a discovery. Although the cognitive divide between individuals engaged in scientific research and those engaged in commercialisation is narrower in biotechnology-intensive industries than in many others (Gittelman and Kogut, 2003), most of the early research on this topic has been centred on the institutional norms that distinguish academic and corporate scientists (open versus closed science). Sauermann and Stephan (2010) show that academic and industrial scientists differ in four key dimensions: basic versus applied research; freedom to pursue research questions; preference for particular tasks (e.g. a 'taste for science'); and different disclosure mechanisms (e.g. patenting, publications and conferences). Traditionally, the decision to start a firm is considered a means for academics to commercialise knowledge created in the university lab and gain a higher income than they can as employees only (Corolleur et al., 2004). Through entrepreneurship, scientists are able to appropriate returns from knowledge and the ideas that they have created within the incumbent organisations (Audretsch et al. 2007).

Previous research demonstrates that the transition into entrepreneurship becomes more likely when scientists have a good run of research, measured in terms of publication count, and a discovery that has potential commercial value (Ding and Choi, 2011). Early in their careers, scientists establish their reputations based on publication, whereas in the later stages, there are incentives to trade or cash in on their reputations for economic return, for example, by establishing a new firm (Audretsch, 2001). Academics with the intention of creating their own companies display a more positive attitude towards risk than those who engage only in advisory or consultation activities (Corolleur et al., 2004; Ding and Choi, 2011). The most experienced academics are in the best position to run radical, high-risk innovation projects, but to boost the chances of these projects achieving success, academics often go into partnership with other scientists who have complementary experience in business.

With the birth of science-intensive industries such as biotechnology, firms began attracting scientists to join their organisations, offering incentives to publish their research findings and to collaborate with leading academic scientists (Helfat et al., 2009). Corporate scientists are important in enabling companies to absorb external knowledge (Herrera and Nieto, 2015). Additionally, they serve to facilitate knowledge circulation by providing access to university equipment in a firm's early development (Corolleur et al., 2004). This creates the conditions for a learning process to unfold between the scientist's previous academic lab and the start-up. Furukawa and Goto (2006) found that corporate scientists with a high number of publications promote patent applications of co-authors in their companies, and thus have the potential to serve as a bridge between their company and the external sources of knowledge. Tzabbar et al. (2013) highlighted that knowledge integration occurs when the hiring firm's patent cites both its own patents and those of its hired scientists. Kim et al. (2005) investigated the relationship between firms patenting propensity and scientists' mobility rates and found that firms use patents to minimise the harm caused by the departing scientists. Furthermore, Melero et al. (2020) highlighted that patent protection makes inventors' human capital more firm-specific, and therefore lowers the likelihood of employee's mobility. Prior studies have also shown that patented knowledge which is not utilised commercially by the firm is associated with the creation of new firms through employee entrepreneurship (Gambardella et al. 2015).

Corporate scientists' human capital has various components that affect firms' innovation performance (Herrera, 2020). Some authors consider scientists' skills and education to be important determinants of a firm's innovation success (Burton, 2001; Ding and Choi, 2011). Ding and Choi (2011) found that biotech firms created by PhD founders are more likely to adopt open science strategies. Other studies have studied scientists' role in the process of knowledge transfer and the formation of alliances (Spithoven et al., 2010).

Previous research on the subject emphasises the importance of star-scientist-entrepreneurs, who play a major role in terms of scientific contributions (Almeida et al., 2011; Hess and Rothaermel, 2011; Perkmann et al., 2011; Zucker et al., 2002). The key role was highlighted by four pre-formation entrepreneurial capabilities: technology-market matching; claiming and protecting the invention; attracting and mentoring the founding team; and strategic timing (Thomas et al., 2020). These individual-level capabilities are important extensions of the firm-level dynamic capabilities of sensing, shaping and seizing opportunities (Shane 2003; Teece et al., 1997; Thomas et al., 2020).

An increasing number of scientists have also followed the so-called path of 'dual knowledge' disclosure which is when 'patent-paper pairs' disclose the same 'piece of knowledge' (Murray, 2002, 2007; Ducor, 2000). The focus on dual knowledge allows a concrete empirical starting point from which to identify the impact of intellectual property rights on the rate of scientific knowledge diffusion. By recognising such duality, Stokes (2011) reformulated the traditional distinction between basic and applied research by proposing a new dimension (the 'Pasteur Quadrant') along which 'user-inspired basic research' is motivated by both fundamental scientific interest and potential commercial gain. Furthermore, Gittelman and Kogut (2003) proposed the concept of 'bridging scientists' to describe scientists who engage in both publishing and patenting activities. These scientists span science and its applications, bridging the scientific and technological domains within organisations (Gittelman and Kogut, 2003; Subramanian et al., 2013). Similarly, Breschi and Catalini (2010) asserted the importance of author-inventors in connecting the scientific and technological research communities as 'knowledge brokers' between the publishing and patenting domains. By linking university spin-offs and the concept of dual knowledge into a patent-paper-venture approach, Thomas et al. (2020) revealed how early decisions taken by the star-scientist-entrepreneur lay a strong foundation for the spin-off's pre-formation. Therefore, publishing and patenting activities as well as entrepreneurship are distinctive moments of the progression of science from research laboratory to the marketplace.

2.2 Knowledge appropriation through patent ownership

Given the increasing involvement of universities in commercial activities, patents have become a valid bibliometric indicator of the usefulness and transferability of research outputs (Lissoni, 2012; Meyer, 2000). Patents are considered a useful tool for researchers since they provide a publicly accessible record of the flow of knowledge, with information on the inventors, the assignee, firms' alliances and the type of scientific knowledge related to its technological positioning. Patents allow for knowledge capture by establishing ownership rights over the invention's commercial rewards. Based on this, patenting activity is a strong predictor of the decision to participate in the founding of a firm (Louis et al., 1989; Stuart and Ding, 2006). Indicators of patent ownership have been taken as a measure of the rate at which knowledge is applied commercially. At a theoretical level, corporate ownership could be inefficient if academics do not have incentives to make high-quality contributions. Therefore, by acting as intermediary agencies, universities may help reduce information asymmetries and lower search costs (Hellmann, 2007; Hoppe and Ozdenoren, 2005; Macho-Stadler et al., 2007).

From an empirical standpoint, the research on intellectual property rights disclosures by universities has followed two separate patterns in the US and Europe. In the US, the introduction of the Bayh-Dole Act of 1980, which encouraged the filing of patents by universities over the results of publicly funded research, prompted many scholars to train their attention on patent records. The American model is quite unique in the autonomy it grants to universities in retaining rights over discoveries made by their employees (Lissoni and Montobbio, 2015). Consequently, it was argued that the Bayh-Dole Act increased the propensity for dual knowledge to be disclosed through both scientific publications and patents (Murray, 2007). Nevertheless, individual researchers and institutions varied widely in their response to this new environment (Azoulay et al., 2007; Ding et al., 2006, Mowery et al., 2001, 2002). Analysing a sample of 5811 patents with US faculty inventors, Thursby et al. (2009) reported that 62% of these were assigned solely to universities. Moreover, the authors highlighted that the patents assigned to companies were less original than those assigned to universities.

European legislators have been more hesitant to adopt regulations similar to the Bayh-Dole Act. Many authors describe the EU patent landscape as being a result of the presence of so-called ‘professor privilege’, which allows European academics to retain ownership over the results of their inventions (Von Proff et al., 2012). Until a few years ago, being considered civil servants, most European academic faculty had no disclosure duty towards their universities. This resulted in the majority of academic patents being assigned outside universities. Specifically, the share of academic patents assigned to corporations ranges between 64 and 82% in Europe, compared to 26% in the US (Lissoni et al., 2008). In most countries, however, this privilege was abolished in the early 2000s, with the exceptions of Sweden, which still maintains it, and Italy, which introduced it in 2001 (Lissoni et al., 2008). Moreover, UK and the Netherlands are countries in which universities are largely autonomous, have a tradition of self-administration, and are both free and capable to define their own strategies for raising funds and managing assets. In contrast, the public research system in France is dominated by large public research organisations (PRO).

Lissoni et al. (2012) showed that in Denmark, France, Italy, and Sweden the percentage of patents owned by universities is around 10% or less, as opposed to over 20% for the Netherlands and the UK. These differences, for many, have been reason enough to conclude that Europe is lagging behind the US in terms of the patenting of research outputs. The so-called 'European Paradox' represents an empirical case for the knowledge filter, which is the theoretical reason why investments in science and research do not automatically spill over into the market (Audretsch et al., 2007). However, from a theoretical perspective, although individuals are less well positioned to exploit their inventions than a technology transfer office at a university, inventors still find incentives to approach firms and profit from their own discoveries (Czarnitzki et al., 2012). For example, Sterzi (2013) finds a quality premium in the short term for patents owned by business: company patents show on average 44% more citations than university patents in the first year after priority. Additionally, there is evidence of 'cherry picking' of patents of higher quality, which are initially assigned to universities or PRO and then 'picked' by corporations. Czarnitzki et al. (2012) found that in Germany, assignment to corporations is more likely in the presence of inventions with high blocking potential in certain markets. Through an analysis conducted in five European countries, Lissoni et al. (2012) confirmed that academic patents tend to be less important than non-academic patents. Furthermore, Crespi et al. (2006) distinguished between university-owned patents, that is, those with an academic assignee, and university-invented patents, that is, those with at least one university inventor but not assigned to a university. Interestingly, the authors found that the seemingly poor patenting activity of universities in Europe is due to a lack of university-owned and not university-invented patents, and that these patents differ very little in terms of commercialisation or economic value. To consider the heterogeneity in patent assignation, Belderbos et al. (2014) focused on co-patenting between industrial and university partners. The authors observed a significant positive relationship between co-patents with universities and market valuation and found that university co-patenting allows firms to send a strong signal of embedded relationships. Finally, to compare academic and industry patenting, Sapsalis et al. (2006) considered 400 biotech patents by Belgian universities and firms to analyse determinants of patent value. The results show that patent values for academia and industry react to similar determinants, such as the number of inventors, coassignees and citations of prior patents and non-patent literature.

In the private sector, the rights and liabilities within an employer-employee-inventor relationship are governed by different legal institutions than at academic levels. A common feature in international patent regulations is that inventors have the right to be named in patent applications (Foley et al., 2018). In the United States, the general rule is that the individual inventor owns what he or she has created. Moreover, it is a common practice that employees and employers enter into patent assignment agreements prior to the creation of any patentable inventions (Roiash et al., 2019). In contrast, IPR regulations by European countries often distinguish between work-related inventions such as those made in the course of the employees' work and duties, and inventions arising outside the context of the employment. Work-related inventions are usually transferred to the employers, whereas the remaining inventions are left to the inventors (Harhoff et al., 2007). Also, European legislations are often characterised by compensation schemes for the employees, whereas in the US this is left to companies' discretion (Sandrik et al., 2020; Harhoff et al., 2007). Despite this, there are substantial differences between countries in Europe concerning whether the transfer of inventions is automatic or not, and how creators' rights are regulated (Despot et al., 2019). For example, in Germany the general rule is that the inventor owns the patent, while employers maintain the right to claim the transfer of the ownership or the exclusive licence of use without the need to contract with the employee. In France, employees' inventions are in most cases owned by the employer but, in return, employees are entitled to financial compensations (Declercq et al, 2017).

Overall, countries' regulations governing the assignment and transfer of intellectual property rights involve many aspects which are critical to the management of innovation, such as the trade-off between a firm's capacity to control and coordinate strategic intangible assets and incentives to support and motivate creativity of highly skilled workers and its ability to control the consequences of employee mobility (Coriat et al., 2012).

2.3 Scope of the study

It is clear from the extant literature that scientists play an important role in firms' innovation and that personal involvement is a key aspect for the success of knowledge transfer activities. Furthermore, it is apparent that publishing, patenting and founding a company characterise the whole spectrum of transforming science into business. Nevertheless, most of the work carried out by previous scholars has focused on academics involved in the commercialisation of science and university linkages. Existing studies rely on analyses conducted at the university level, rather than addressing single inventors. Few attempts have been made to consider the heterogeneity of careers among scientists who contribute to the creation of biotechnology enterprises, or to investigate how this heterogeneity affects firms' knowledge appropriation strategies. In this study, we focus on scientific founders of European biotech companies who are also patent inventors and authors of scientific publications. The main objectives are to analyse whether these scientific and professional backgrounds act as antecedents of the entrepreneurial outcome of starting a company and, based on this, to understand to what extent scientists capitalise on earlier knowledge and experience by transferring their inventions to their own start-ups.

The first research question guiding our examination is as follows: What is the scientific human capital of the founders of biotech companies? By looking at biographical information contained in IPO documents, we investigate founders' career trajectories. We also analyse the scientific human capital of the founding scientists in terms of orientation towards publishing and patenting.

The second research question is: To what extent do the inventors' professional and scientific backgrounds, as well as patents characteristics, determine the assignation of intellectual property rights? We hypothesise that inventors' professional background and research expertise may affect the allocation of IPRs and therefore the transfer of knowledge to their start-ups.

3 Materials and methods

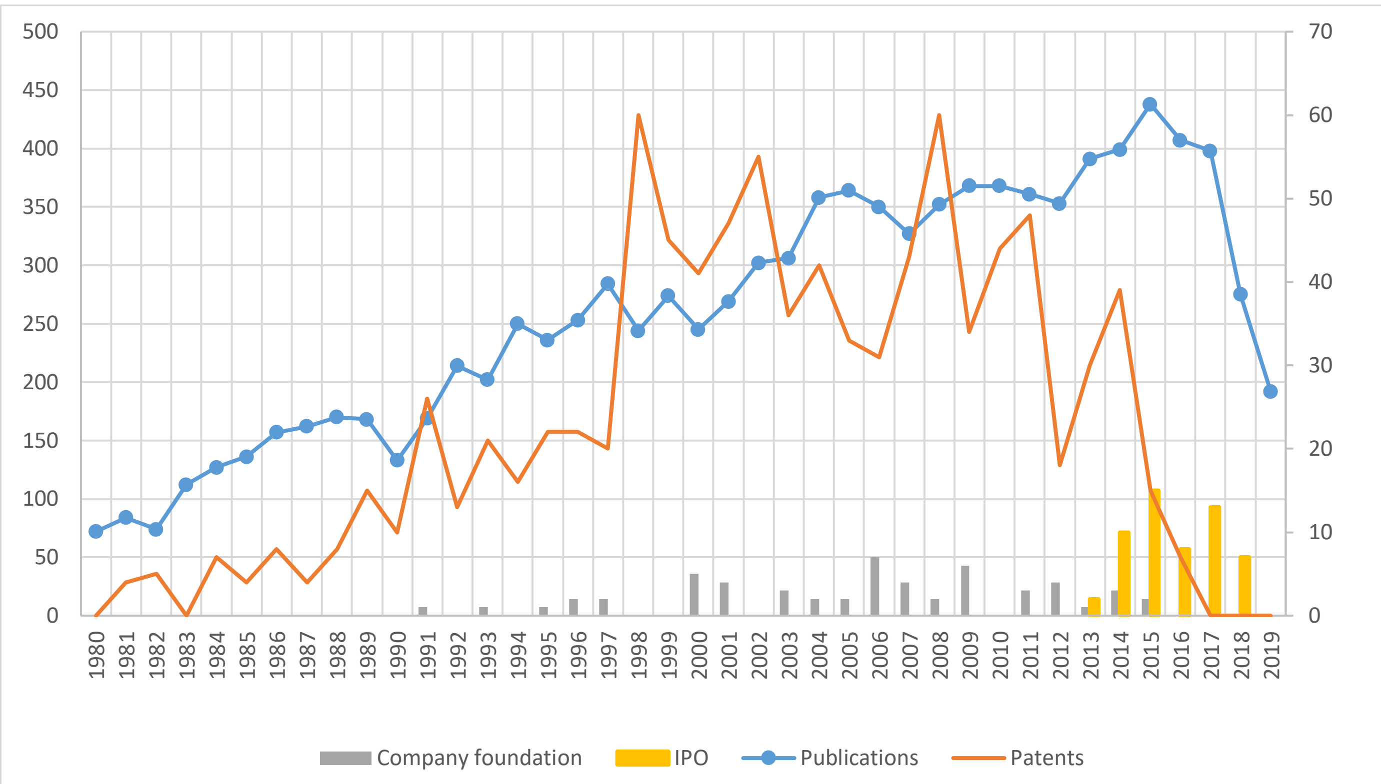
3.1 Sample creation

The initial study sample comprised data on biotechnology companies headquartered in Europe that went public in the period from 2013 to 2018. Only the firms that are 'drug originators', meaning that they conceptualise, discover or initially develop a drug (GlobalData Plc), were included. Our primary interest at this stage was to characterise the company history and identify the names and background of the scientific founders. Companies' biographical sketches were identified from IPO prospectuses and downloaded through the GlobalData directory and companies' own websites. In cases where it proved difficult to identify the required data, information was integrated by searching on crunchbase.com and linkedin.com. Firms for which the biographical data on founders could not be confirmed or was not available in English had to be excluded. Based on the biographical material, we defined scientific founders as those who were at least trained as research or applied doctorates (such as MD or PhD), as well as those engaged in the conception and creation of new knowledge relevant for company creation.

Second, we searched for patents granted to the scientific founders of the biotechnology companies in our sample. Specifically, we downloaded patent data referring to the founders appearing as 'inventors' and grouped by priority documents (http://www.epo.org/searching-for-patents/helpful-resources/first-time-here/patent-families.html). We limited our analysis to patents granted between 1980 and 2019. Pending patent applications were excluded. Furthermore, scientific publications authored by the scientific founders were downloaded. We searched for articles published in English in peer-reviewed scientific journals between 1970 and 2019. Meeting abstracts, commentaries and reviews were excluded.

Patent and publication data were downloaded from 'The Lens' suite (https://www.lens.org/lens/), an integrated initiative by CAMBIA. The database comprises the European Patent Office (DOCDB) bibliographic data, the United States Patent Office (USPTO) database, data from the World Intellectual Property Organization (WIPO-PCT), and Australian patents (Jefferson, 2018). 'The Lens' is considered one of the most complete free-to-use databases for analysis of the biotechnology sector (Jürgens et al. 2018). For our purposes, the advantages of 'The Lens' patent database were several: first, inventor names were linked with social web directories (LinkedIn and ORCID); second, by collecting data from the same source for patents and publications (Lens.org), we were able to match inventors', authors' and founders' names; and lastly, 'The Lens' provides links to non-patent literature (NPL) cited by applicants, which was also downloaded together with the patent information.

Further data cleansing was performed to avoid disambiguation issues. First, we manually inspected whether the affiliations reported in the scholarly papers and those in the patent were consistent with the biography material. Second, we checked for patent duplicates, and we eliminated those entries for which the inventor and the company affiliation were identical. Our selection process produced 10,711 unique publications and 932 patents associated with 80 different authors/inventors figuring as the scientific founders of 55 EU-based, drug-originating biotechnology companies that went public between 2013 and 2018. In Fig. 1, we report some descriptive statistics related to the final sample.



Years	Number of Patents (%)	Number of Publications (%)	Number of Company foundation (%)	Headquarter location	Number of companies (%)
< 1990	65 (7%)	1762 (16%)		France	11 (20%)
1991 - 2000	286 (31%)	2371 (22%)	12 (22%)	Sweden	10 (18%)
2001 - 2010	425 (46%)	3364 (31%)	30 (30%)	United Kingdom	9 (16%)
2011 - 2019	157 (17%)	3214 (30%)	13 (24%)	Netherlands	4 (7%)
				Denmark	4 (7%)

Tot	932	10711	55	Other EU countries	17 (31%) 55

Fig. 1. Sample descriptive statistics.

3.2 Data analysis

In this section, we present the steps followed to identify and analyse the data on founders, patents and publications. The careers of the biotech scientific founders were categorised based on the biographical material retrieved from IPO prospectuses and company websites. Specifically, we distinguished between founders with academic experience (including positions in hospitals, research foundations and government) and founders with working experience within for-profit organisations (Audretsch, 2001; Clarysse et al., 2011; Meoli et al., 2013). Two co-authors independently scanned, collected, and performed a blind reading of the biographical material for every founder in the sample. Based on the classification employed by Audretsch, 2001, this information was used to distinguish between three distinct career trajectories:

1. The *industrial trajectory* describes scientists whose careers had been mostly spent working in the industry.
2. The *academic trajectory* includes scientists who had spent most of their careers working for academic institutions and PROs.
3. The *mixed trajectory* describes scientists who held positions in both industrial and academic research settings.

In the Appendix, we report some extracts from the biographical material as evidence of the approach used for career classification. Building on Subramanian et al. (2013), Baba et al.

(2009), Hess and Rothaermel (2011), and Stokes (2011), we further categorised the scientists based on their propensities towards publishing and patenting. The average number of patents and publications per year was calculated based on the years in which each scientist had been active, meaning the number of years between the first and the last publication/patent. The scientific production of each scientist was then compared to the mean number of patents/publications of the sample. Accordingly, scientific profiles were defined as follows:

1. *Pasteur bridging scientists* were those with above-average per-year patenting and publication records.
2. *Edison scientists* were defined by above-average patenting records but below-average publication records per year.
3. *Star non-patenting scientists* were those with above-average yearly publication records but below-average annual patents.

Finally, patent assignments were analysed to identify the types of patent assignment. We refer to patent assignees or applicants as the individuals or organisations owning the application for an original patent, and therefore showing sufficient proprietary interest in the matter. Despite this, the terms ‘assignee’, ‘applicant’, ‘ownership’ and their derivations are used interchangeably throughout the text.

Assignees were categorised according to Eurostat’s project on Data Production Methods for Harmonised Patent Statistics (Callaert et al., 2011). In particular, we checked whether the assignee names contained business designations or not-for-profit entity names. In order to identify patents assigned to the start-up companies we matched the names of assignees with those of the companies belonging to our initial sample. We checked on the remaining private assignee names to identify whether the scientific founders were also involved in the foundation of companies not included in our initial sample but reported in the biographical material[1]. Following a similar approach, we identified the patent assigned to the inventors' employers so to establish whether the ownership of patent rights was claimed under an employer-employee agreement. Unassigned patents were those assigned not to organisations but to individuals (Callaert et al., 2011). Patent locations were categorised according to companies' headquarters and founders' university addresses as reported in the biographical material. In 16 cases, we were not able to classify the assignee, and hence we dropped these patents from our analysis.

4 Results

In this section, we illustrate the results of some descriptive analyses based on the biographical information and the scientific material attributed to the scientists in our sample. First, we focus on scientists' scientific human capital by reporting their professional trajectories and scientific experience in patenting and publishing. Then, we provide descriptive results on patent assignations.

4.1 Founders' scientific human capital

The scientific founders of biotech companies showed different career patterns and degrees of involvement in the production of science.

4.1.1 Careers trajectories

[1] We found 17 companies started by the scientific founders and not included in the initial sample.

In our sample, we found that 38.5% of scientific founders held academic positions or working experience in PROs (*academic trajectory)*. Scientists followed an *industrial trajectory* in 31.3%, and in 30.2% they reported professional experiences in academia as well as in profit-led organisations (*mixed trajectory)*. Furthermore, we found that 46% of scientists with industrial background and 32% with mixed careers had prior working experience at large incumbent pharmaceutical firms.

Overall, by looking at the biotech founding teams we found that 16 start-ups (29%) were launched by a combination of scientists with different career backgrounds. The most recurring team was composed of founders with careers in the industry and mixed backgrounds (31%), whereas in 25% biotech were started by founders with academic career together with mixed scientists.

4.1.2 Scientific profiles

Our bibliometric data showed that scientists started their companies 17.2 (SD 12.2) years after their first publication and 8.4 (SD 8.25) years after their first patent application. Scientists' publication history covered, on average, 27.6 years (SD 15.2), and their patenting history 13.2 (SD 9.1) years. This was calculated as the distance in time between the first and the last publication/patent. During this time, on average, the founders produced 4.1 (SD 3.99) publications and 1.2 (SD 0.89) patent applications per year. Of these, 46.6% of articles and 51.6% of patents pre-dated the company's incorporation.

In Fig. 2, we plot the founders' propensities towards science as highlighted by the annual count of publications and patents. The horizontal and vertical lines indicate the average number of yearly publications and patents based on the whole sample of biotech founders. Each point in the graph represents a scientific founder, who is positioned based on the combination of the average patents/publications produced over time. Career trajectories are also included to highlight the interrelation between scientific and professional experience. The founders with a focus on both publications and patents (Pasteur scientists) account for 11.3%. This category identifies those scientists who are in a strong position to connect technology and science and who, from a firm's perspective, contribute to transforming scientific discoveries into useful inventions with commercial value. Pasteur scientists also reduce firms' dependence on external scientific knowledge (Gittelman and Kogut, 2003; Subramanian et al., 2013). However, 20% of the scientists had a greater propensity towards patenting. This type of scientist plays a complementary role in collaborations between firms and academia. Moreover, based on their higher patenting propensity, Edison scientists are also able to enhance the R&D activities of a firm (Subramanian et al., 2013). A significant number of founders (20%) were found to have higher than average publication rates and low patent production (star non-patenting scientists). According to Polidoro Jr and Theeke (2012), a higher focus on science may favourably influence the assessment of firms' products by regulatory agencies. Additionally, by having a 'taste' for science, the scientists in this latter group are also in a better position to engage with the scientific community, which improves firms' reputations (Roach and Sauermann, 2010; Stern, 2004).

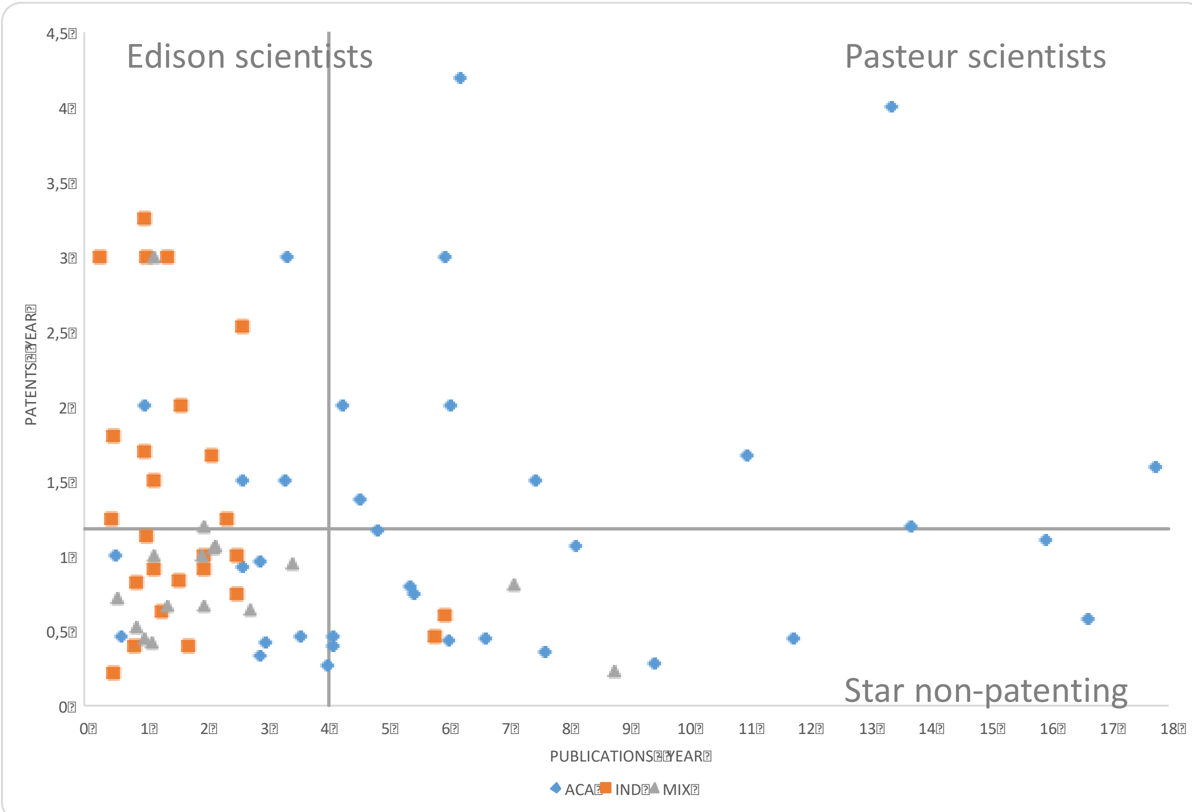


Fig. 2. Founders' scientific profiles.

Legend: *ACA – academic trajectory; IND – industrial trajectory; MIX – mixed trajectory. Vertical line: sample average yearly publications. Horizontal line: sample average yearly patents.*

We found that the great majority of the founders in the Pasteur and Star quadrants were academics (87.55%), whereas the founders with industrial career backgrounds were more involved in patenting activities: 60% of the Edison scientists were practitioners. Scientists with no higher-than-average publications and patent records showed in 41% mixed career trajectories across academia and industry. A chi-square test of independence was performed to examine the relationship between career trajectories and type of scientists. The difference in proportions between these variables was significant: X2 (8, N= 80) = 40.6, p = .00.

Overall, these results confirm that publishing and patenting require different skills; however, the involvement of scientists in the foundation of biotech enterprises requires a mix of practical and conceptual expertise to transform science into commercial products.

4.2 Patent ownership

The percentage of patents by biotech founders which are owned by business companies was, on average, 76.1%. Universities and PROs were found in 12.8% of the patent sample. Patents with multiple assignments accounted for 7.3% of the total, with the most frequent type of co-assignment being between corporations and universities (57 patents, 6.1%). Different ownership types were found between patents by academic inventors compared with practitioners. Faculty inventors assigned 64.5% of their patents to corporations and 24% to universities whereas industrial scientists did so in 89.3% and 3.2% of the patents respectively (see Table 1).

Table 1. Types of patent assignment by the inventors' professional trajectories.

	Type of Assignment										
Inventors' career trajectories	CORP		UNIV&PRO		UNASS		CORP&UNI		CORP&UNASS		Total
	n	%	n	%	n	%	n	%	n	%	
ACA	252	64.5%	94	24.0%	25	6.4%	19	4.9%	1	0.3%	391
INDU	251	89.3%	9	3.2%	4	1.4%	15	5.3%	2	0.7%	281
MIX	207	79.2%	16	6.1%	7	2.7%	23	8.8%	8	3.1%	260
Total	709	76.1%	119	12.8%	36	3.9%	57	6.1%	11	1.2%	932

Legend: *CORP – corporations; UNIV – universities; PRO - public research organisations; UNASS – unassigned*

We found that a large number of the patents owned by business corporations was explained by those assigned to start-up companies (57.4%). Specifically, start-ups appeared on 50.1% of the patents filed by academic inventors, 41.3% of patents by industrial inventors, and 36.5% by mixed scientists. 57% of patents with multiple assignees were co-owned by start-up companies and universities. Existing literature indicates that co-patenting with universities places firms in a favourable position with respect to absorbing new knowledge and thus generates relatively strong investor responses. Further, co-patenting was also found relevant for developing products or services of a more novel nature (Belderbos et al. 2014).

Another segment of privately-owned patents was characterised by the companies in which industrial and mixed scientists were employed (22.6%). In fact, in the 31.3% of the patents by industrial scientists, corporate assignees were also the inventor's employer. Similarly, prior employers were found in 32.3% patents filed by inventors with mixed careers (of which 17.8% were universities and PROs and 82.1% corporations). Universities and public research institutes in which inventors were employed were found in 25.5% of the patents by academics. Lastly, large incumbent pharmaceutical companies were identified in 12% of the patents assigned to corporations by industrial inventors and in 2% of those by academics.

Academic patents were further analysed in order to investigate the different ownership models at country level. Our results indicate that company ownership of academic patents differ markedly across EU countries. Specifically, we found that the percentage of patents owned by corporations was particularly high in Norway (100%), Germany (91%), the Netherlands (86%) and Sweden (83%). In these countries the large portion of privately owned patents was explained, in most part, by the assignation of IPRs to companies founded by academic inventors. In contrast, a high share of patents owned by universities and PROs was found in France (59.5%) and the United Kingdom (59.3%). Multiple assignations were also quite diffuse, i.e. countries with stronger university ownership.

Overall, the percentage of academic patents owned by corporations (64.5%) is in line with evidence by previous studies such as (Lissoni et al., 2008). However, countries with stronger university and PROs statuses and autonomy, such as the UK and France, exhibit higher percentages of patents owned by universities and PROs (59% in our study compared with 17% by Lissoni et al. (2012)). Importantly, we notice that in these countries the number of patents co-owned by public and private actors is also high. In countries with stronger professor independence, such as Scandinavian and Germany, we find a higher percentage of patents owned by corporations than previous studies, the majority of which are start-up companies.

Therefore, it seems that when it comes to analysing the patents by academics who are also biotech founders, the differences at country levels become more polarised. One interpretation could be that in the light of potential economic returns, professors on the one side, and universities on the other are incentivised to use the full range of legal prescription and cultural influence, in order to retain the ownership of intellectual property rights. In this way, the possibility for the inventor to dispose of his or her IP (due either to law or custom) is likely to foster a different system of relationships between inventor, university and industry, with respect to countries where institutional ownership has traditionally been present and enforced (Geuna et al. 2011).

These arguments are further examined in the next section, where patent characteristics together with inventors' professional and scientific backgrounds are tested on the extent to which they influence the appropriation of IPRs by biotech start-ups.

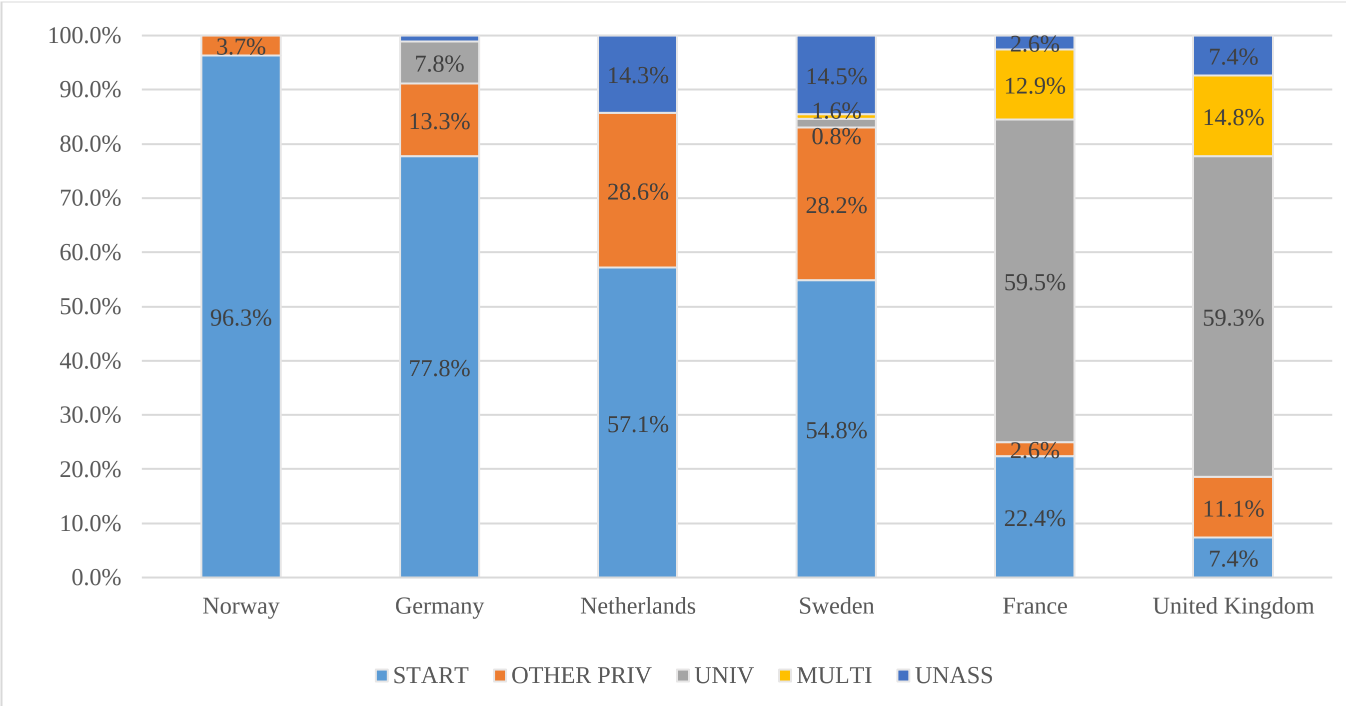


Fig. 3. Distribution of academic patent ownership by country.

5 Econometric model

In this section, we use a multinomial logit model to explore the relationship between patent assignment and the characteristics of patent documents and inventors' professional careers. By adopting the following econometric model, we assume a causal relation between the founders' career trajectories, patent characteristics, and type of patent ownership. We focus on the scientific founders acting as patent inventors; therefore, the words 'scientists', 'founders' and 'inventors' are used interchangeably.

5.1 Dependent variable

The dependent variable was built as a combination of the patent categories and the information illustrated in Section 4.2. Patents assignations were categorised into five levels, distinguishing between the assignation to the start-ups and the companies or institutions in which the inventor was previously employed. The categories and the shorthand notation for each level are as follows:

1. START_UP: the patent is assigned to a firm founded by any of the scientists in our sample.
2. EMPLOY: the patent is assigned to a firm or to a public institution in which a job link could be found between the firm/institution and the scientist(s).
3. OTHER: the patent is assigned to a firm or institution in which a link could not be found between the firm/institution and the scientist(s).
4. MULTI: the patent has multiple assignees as a combination of the previous levels (1&2, 2&3, 1&3 or 1&2&3).
5. UNASS: the patent is unassigned and therefore owned by the inventor(s).

5.2 Independent variables

We expect patent assignment to be driven by the combined effects of inventors' professional trajectories and scientific experience as well as by patent characteristics.

The first independent variable corresponds to the professional trajectories as depicted in Section 4.1. We adopted two measures that look retrospectively at the scientific experience of the inventors before the time of patent application. The first backward-looking variable is the number of publications made in the ten years before the patent application (PUBL_MADE10BF) (Azoulay et al., 2005; Stuart et al., 2007). The second backward-looking variable is the number of patents granted in the ten years before the patent (PAT_MADE10BF) (Czarnitzki et al., 2009; Mowery et al., 2002; Sterzi, 2013). By including these variables, we could test whether the combined experience of researching and patenting determines patent assignations. In contrast to section 4.1, the former two variables were built as measures of the founders' scientific activity to assess whether the patent resulted out of a more or less intense line of research. As such, the decision to restrict these measures to the ten years before the patent reflected an estimated average time required for publishing and patenting. However, as pointed out by Sterzi (2013), these measures are linked to the inventor and not to the patent, and it is possible that a patent has more than one inventor. To control for this aspect, we included the number of inventors, which is also adopted as proxy of collaborative research efforts (Czarnitzki et al., 2009). Moreover, we included the number of assignees, which represents the extent of collaboration efforts between organisations of the same kind, and is a measure of patent value (Sapsalis et al. 2006 Sterzi, 2013).

Based on the publications authored by the patent inventor, we built a variable describing the level of 'research applicability', meaning the propensity to publish on applied topics. In line with Du et al. (2019), we focused on three dimensions: 1) whether the research was disease-oriented; 2) whether it was patient-focused; and 3) whether the study clearly stated the intention to develop future therapeutic applications. We based our classification of the first two aspects on the Medical Subject Heading (MeSH) terms found in the publications authored by the scientific founders included in our sample. Our purpose was to determine whether the research published before the patent application was made with an eye more towards future practical application than towards fundamental research. Papers published by the scientific founders during the ten years before the patent priority date were classified as *disease-targeted* if at least one MeSH Major Topic term corresponded to a disease (i.e. the MeSH code starts with the letter C), and *human-targeted* when the MeSH controlled vocabulary includes a term for 'humans'. Finally, publications with titles and/or abstract fields containing the words 'therapy', 'therapies', 'therapeutic', 'therapeutical', 'prevention', 'preventive', 'vaccine', 'vaccines', or 'clinical' were labelled *therapy targeted.* In conclusion, we regarded 'disease-, human- and therapy-targeted' publications as ‘applied’ research. Based on this, we built a scale measure by weighting the number of MeSH measures, and we created a variable (named ‘APPLICABILITY’) that ranges from 1, meaning ‘basic’ research, to 10, meaning ‘applied’ research.

The regression also includes the number of citations to prior patents (BACKW_CIT). We assumed that the larger the number of backward citations, the more extended the body of related work and therefore the more incremental the patent (Thursby et al., 2009). Moreover, the number of forward citations (FORWD_CIT) received by the patents by December 2019 was included to reflect importance, in the sense that the patent had been considered existing material by either subsequent inventors or patent examiners. However, this measure was subject to error truncation. For example, the patents granted between 1981 and 2000 had, on average, 8.05 citations whereas the average citations to the patents granted from 2005 onwards was 0.45. For this reason, we mitigated the effect of truncation by weighting the number of citations for number of years between the patents’ early priority year and a base year (2019). Despite this, the variable was never significant, and therefore we have not included it in the final model. As a check, we deleted all patents applied for after 2000, which resulted in a sample composed of just over 300 observations. While this does not completely rid the data of truncation, it does mitigate further problems.

Another patent regressor is expressed by the number of non-patent articles (NPL_CIT). Non-patent literature is a general indicator of science-technology linkages legitimising basic research activities (Czarnitzki et al., 2009; Meyer, 2000). Citations of scientific literature demonstrate the linkage of technology to scientific knowledge and the extent to which patents are situated within the ‘vicinity’ of scientific knowledge (Callaert et al., 2006). In this respect, patent citation studies capture what Nelson (1998) calls a ‘body of understanding’ rather than a ‘body of practice’ (Meyer, 2000; Pavitt, 1998).

5.3 Controls

Time and technology control variables were included. We built the former by accounting for patent priority years for patents made after 2000. Until that year, many European countries were characterised by the 'professor privilege', and therefore, we controlled for any changes that occurred after that. The latter was built based on the IPC categorisation, a hierarchical system of language-independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain, and according to the World Intellectual Property Organization (WIPO). In our model, we accounted for the first letter of the IPC symbols reported on the patent document. Lastly, since many inventors held more than one patent, we performed our multinomial regression on stratified complex samples based on inventor IDs weighted by the total number of patents held by each unique inventor. In Table 2, we report the descriptive statistics with reference to all variables employed in the empirical analysis, while Table 2 in the Appendix reports the correlation matrix.

Table 2. Overview of independent variables.

Variables	Description	Measurement	N	Minimum	Maximum	Mean	Std. Deviation
Professional trajectory	Academic, industrial, mixed	categorical	932	1	3	2.02	0.76
Number of previous patents	Number of patents made in the ten years before patent application	numerical	932	1	47	9.80	9.04
Number of previous publications	Number of publications made in the ten years before patent application	numerical	835	1	323	44.54	47.96
Applicability	Propensity to publish on applied topics in the ten years before patent application	ordinal	932	1	10	5.98	3.05
Backward citations	Number of patent citations	numerical	922	0	168	6.21	17.12

Number of assignees	Number of patent assignees	numerical	932	1	17	1.85	1.98
Number of inventors	Number of patent inventors	numerical	932	1	27	4.02	2.47
NPL citations	Number of non-patent citations	numerical	932	0	224	8.66	24.12

5.3 Multinomial logistic regression

Table 3 shows the results of our multinomial logistic regression in terms of relative risk ratios (RRRs). When RRR values are greater (smaller) than one, the increase in the independent variable is associated with an increase (decrease) in the risk of patent assignment relative to another level in the dependent variable. For example, in Panel A. START UP/EMPLOY, we report the risk of patent assignment to the companies founded by the scientists in our sample (START UP) relative to the assignment to the inventors' employers. Panels B and C are comparisons between patents assigned to start-ups and those assigned to other companies or institutions (OTHER), a combination of these (MULTI), or left unassigned (UNASS). Finally, in Panel E, F and G, patents owned by employers (EMPLOY) are compared with other companies/institutions (OTHER), multiple assignees (MULTI), and chances to be left unassigned (UNASS). Panel H, I, and L are the remaining combinations involving OTHER, MULTI, and UNASS.

We tested the irrelevance of independent alternatives (IIA) assumption based on Hausman and McFadden's (1984) work. The results of the test were inconclusive, thus supporting the independence assumption. We also performed a likelihood-ratio (LR) test on combinations of alternatives to determine whether categories could be collapsed. The LR test rejects the hypothesis; thus, our approach was appropriate.

Table 3. Multivariate logit assignment results.

	A. STARTUP/ EMPLOY		B. START UP/OTHER		C. START UP/MULTI		D. START UP/UNASS		E. EMPLOY/ OTHER		F. EMPLOY/ MULTI		G. EMPLOY/ UNASS	
Inventor professional trajectory	**RRR**	**t-ratio**	**RRR**	**t-ratio**	**RRR**	**t-ratio**	**RRR**	**t-ratio**	**RRR**	**t-ratio**	**RRR**	**t-ratio**	**RRR**	**t-ratio**
Mixed	1.802	2.45**	3.081	2.66***	0.278	-2.64***	0.709	-0.38	1.710	1.35	0.154	-3.97***	0.393	-1.07
Academic	7.840	8.83***	4.012	3.98***	2.250	1.460	0.836	-0.23	0.512	-1.96**	0.287	-2.23**	0.107	-2.91***
Inventor scientific experience														
No. previous patents	1.055	5.66***	1.082	4.72***	1.156	4.48***	1.157	3.06***	1.026	1.48	1.096	2.83***	1.096	1.95*
No. previous publications	0.991	-4.27***	0.993	-2.30**	1.016	1.77*	0.985	-3.19***	1.002	0.70	1.026	2.75***	0.994	-1.25
Applicability	1.054	1.69**	1.137	2.56	1.547	4.86***	1.034	0.32	1.078	1.52	1.468	4.25***	0.981	-0.19
Patent characteristics														
Backward citations	1.003	0.29	0.951	-3.10**	1.013	0.628	0.983	-0.78	0.949	-3.09***	1.010	0.484	0.981	-0.89
Number of assignees	0.904	-1.61	0.963	-0.37	0.502	-7.46***	0.574	-3.89***	1.065	0.62	0.555	-7.49***	0.635	-3.55***
Number of inventors	0.972	-0.56	0.832	-2.79***	1.362	2.47**	1.043	0.20	0.856	-2.30**	1.401	2.76***	1.073	0.34
NPL citations	0.998	-0.30	1.073	2.99***	1.007	0.567	1.033	1.52	1.075	3.03***	1.009	0.714	1.035	1.60

Time control	yes
Technology control	yes
Strata	72
Observations	932
R-square - Cox and Snell	0.571

* p<.1; ** p<.05; *** p<.01

Table 3. Multivariate logit assignment results *(cont.)*.

	H. OTHER/MULTI		**I. OTHER/UNASS**		**L. MULTI/UNASS**	
Inventor professional trajectory	**RRR**	**t-ratio**	**RRR**	**t-ratio**	**RRR**	**t-ratio**
Mixed	0.090	-4.36***	0.230	-1.63	2.552	0.94
Academic	0.561	-0.97	0.208	-2.01**	0.371	-1.07
Inventor scientific experience						
Number of previous patents	1.068	1.89*	1.068	1.37	1.000	0.00
Number of previous publications	1.023	2.42**	0.992	-1.69**	0.970	-3.08***
Applicability	1.361	3.14***	0.910	-0.87	0.668	-2.96***
Patent characteristics						
Backward citations	1.065	2.38**	1.034	1.68**	0.971	-1.01
No. assignees	0.521	-5.51***	0.596	-3.48***	1.144	1.15
No. inventors	1.636	3.81***	1.253	1.07	0.766	-1.24
NPL citations	0.938	-2.39**	0.963	-1.31	1.026	1.08

5.3.1 Inventors' professional trajectories

We found that academic founders and those with mixed career trajectories, compared to practitioners, show a higher probability of transferring their inventions to start-ups rather than to employers. Academics, compared with industrial scientists, have also a higher likelihood of assigning their patents to companies and institutions other than those they had worked for (Panel E, F, and G). Patents made by academics are more likely assigned to the start-ups or owned by the academic inventor (UNASS) than all the other alternatives. Founders with mixed career trajectories show similar patterns to those of academics. An exception is when the comparison involves multiple assignments. In this case, there is evidence that founders with mixed careers across academia and industry, compared to industrial inventors, have a higher likelihood of disseminating their inventions to a combination of actors across the public and private sectors than to other companies, employers or others (Panels C, F, and H).

Overall, patents made by academic scientists and those with mixed experience in academia and industry are more often assigned to start-up companies. Therefore, biotech start-ups are more likely to capture the patents by inventors with at least some working experience in academia.

5.3.2 Inventors' scientific experience

As shown in Panels A, B, C and D of Table 3, greater experience in patenting, expressed by the number of previous patents, increases the likelihood of start-up assignments. In contrast, when inventors have a higher number of previous publications, the likelihood of start-up assignment decreases (Panels A, B and D). Furthermore, there is positive evidence that a higher number of previous publications increases the probability of assignment to employers and others compared with multiple assignees (Panels F and H). Inventors' publishing productivity on applied topics increases the likelihood of a start-up patent assignment (Panels A, B, and C), although is also negatively related to multiple ownership (Panels F and H).

Overall, patents by scientists with a more applied scientific experience (run of previous patents and publications on applied topics) are positively associated with start-up ownership. The inventors' applied experience is a factor characterising the appropriation of knowledge by start-up companies.

5.3.3 Patent characteristics

We find that the number of backward citations is more positively related to 'OTHER' than inventor's start-up, employers and to unassigned ownership (Panels B, E, and I). However, the other measure of patent importance (forward citations) is never significant. In the reduced sample composed of the patents applications prior to 2000, the results suggest that forward citations are a factor strengthening the likelihood of patents owned by start-ups rather than by the inventors' employers. However, as we cautioned earlier, care must be taken in interpreting the results of our forward citations variable because of truncation error. The amount of NPL cited in the patent application has a positive impact on assignment to the start-up companies compared to other actors (Panel B). Lastly, the number of assignees positively correlates with unassigned and multiple assignment patents (Panels C, D, F-I). The size of the inventing team has a slightly more significant impact on patents assigned to OTHER than the remaining categories (Panels B, C, E, F and H). This suggests that inventions made by numerous teams are rather owned by assignees of the same kind.

Overall, the interpretation of patent characteristics is less clear. These factors do not affect the comparison between start-ups and employers. When knowledge is incremental, it more likely goes to inventors, multiple assignees or other organisations.

6 Discussion

This paper analysed the scientific and professional profiles of 83 scientists, founders of European biotechnology companies that originated new drugs and went public between 2013 and 2018. We combined the evidence from these founders' biographies with the analysis of patents and publications in order to investigate the transforming function of scientists in the process of knowledge creation and value appropriation. Our study represents the first attempt to combine the literature on knowledge and technology transfer with that of scientific and technical (S&T) human capital and scientific entrepreneurship. To our knowledge this is the first study analysing the profiles of biotech scientific founders and providing empirical evidence on the roles they play as bridging scientists between academia and industry. Previous studies were missing a substantial part of the inventive activity, which comes from the scientists working at industrial level and those with mixed careers in both the public and private sectors. Our study makes two central contributions.

First, in an attempt to provide empirical evidence to the theoretical framework elaborated by Stokes (2011), Baba et al. (2009) and further developed by Subramanian et al. (2013), we find the scientific human and technical capital of biotech founders is characterised by three main trajectories. The first is composed by Pasteur and star scientists, that show higher than average publication and patent records and spend most of their careers working in universities. In contrast, scientists with industrial experience and those with mixed careers show higher patent than publication counts. This division of labour between academics and practitioners finds justification in the extant literature, showing that job incentives between workers in academia and industry differ substantially (Dietz et al. 2005). A surprising aspect comes from the observation of scientists with mixed career trajectories. In fact, if we look at the results of our multinomial regression, mixed scientists show a similar likelihood of assigning patent ownership to start-ups than the academics. As shown by Dietz et al. (2013), intersectoral changes in jobs throughout the scientists' careers are more plausible in explaining patent than publication productivity. While confirming this phenomenon, our study adds a further element, which is that revolving doors between academia and industry may have the effect of enhancing patent appropriation by start-ups. More research is needed on this topic. Scholars and policymakers may find it interesting to consider the combined effects of patent laws and employment contracts on the appropriation strategies by biotech start-ups. One hypothesis could be that mixed career scientists position themselves strategically between the public and private domains in order to maximise financial rewards or minimise entrepreneurial risks. This may have important implications on the organisation of university technology transfer offices (TTO), and the extent to which scientists bypass formal university channels such as TTOs and take their discoveries directly to market. Markman et al. (2008) pointed out that faculty members appear to have greater bypassing opportunities when they are embedded in a context of entrepreneurial activity. However, despite being inclined to commercialiation, scientists often face a tension between the culture of science and that of business. This is reflected in the fact that they often retreat into science after experiencing negative commercialisation outcomes (Gurdon et al., 2010). However, while recognising that the impacts of intersectoral career transitions are complex, this study supports the nature of accumulating S&T human capital in multiple settings (Dietz et al. 2013).

A second contribution stems from the analysis of patent ownership by academics. For a long time, scholars have debated about the presence of a private ownership model in Europe. A number of legal and institutional factors have been considered to explain the relative weight of corporate-owned over university-owned patents. While confirming that most of the patents invented by founders that were also faculty staff were assigned to corporations, we show that a large portion of these enterprises were the companies founded by the patent inventors. Furthermore, we found that countries with a weaker university ownership system, such as those where the professor's privilege is still in place or recently abolished, were associated with a higher proportion of patents assigned directly to start-ups. Moreover, in our multinomial regression we show that higher publication propensities and career trajectories in academia, compared with those in industry, are factors increasing the likelihood of start-ups' appropriation of patents by academics. These findings provide important elements for contributing to the debate on whether it is right or wrong to push European universities to follow the US ones in their efforts to expand patent portfolios. In fact, knowing the size of academic patent portfolios owned by private organisations is relevant in monitoring the effect of reforms that have abolished the professor privilege. For example, Hvide et al. (2018) found that the effect of abolishing the professor privilege in Norway was accompanied by a 50% decline in both entrepreneurship and patenting rates by university researchers. Recognising this, together with the importance of investments in knowledge creation by universities (Fabiano et al. 2019), one can support reforms that include a royalty-sharing regime that favours balancing rights across all parties involved in the early stages of the innovation process. For example, Markman et al. (2008) found that the use of incentives in the form of royalty sharing helps to counteract scientists' inclination to engage in bypassing activity. At the same time, policy reforms should balance the effects on the incentives to produce quality patents and engage in entrepreneurial activities with the introduction of compensation schemes.

Our study contains some limitations that also open opportunities for further research. First, our methodology's bibliometric techniques have some implicit limitations with regards to author and inventor identities and to the collection of associated patents and publications. Limitations also occur due to the combination of sources of different kinds, such as companies' websites and the sources employed for retrieving biographical materials. Consequently, we were unable to perform temporal analyses of the events characterising the founders' careers such as distinguishing founders' professional hierarchies at different points in time over their careers. Similarly, given the narrative nature of the collected data, we were unable to further expand on the diversity of career trajectories based, for example, on job seniority.

Whilst conservative approaches, such as blind reading of the materials, cross-referencing and snowball checks were adopted, the process involved the subjectivity of the authors. Future availability of tools for text analysis would allow the reliability of bibliometric measures, such as on the acknowledgment sections of publications or revenue shares disclosed by patent documents. These would open avenues for contributing to the analysis of financial antecedents of innovations by enhancing the explanatory potential of bottom-up approaches based on document analyses. Additional research might also consider employing different indicators of technology transfer performance, such as revenues earned from commercialisation activities. Lastly, by focusing here on the knowledge that successfully reached the market through IPO, a large part of the scientific efforts, the share that fails to translate into valuable products, was left out of our analysis. Moreover, by focusing on patent assignees, we did not consider the potential changes in ownership that may have occurred at later stages after the patent was granted. Future analyses might therefore centre on ownership changes of patents undergoing reassignment in order to deepen the knowledge of appropriation issues by extending the analysis to the whole spectrum of actors involved in the innovation process.

7 Conclusions

Our study serves to highlight that the knowledge base upon which biotechnology start-ups are created is made collectively by actors with heterogeneous scientific and career backgrounds. However, these give a specific direction to the appropriation of knowledge by biotech companies. In particular, spending part or all of a career working in a university increases the likelihood of patent appropriation by biotechnology start-ups. Therefore, biotechnology companies that reach IPO in Europe are the result of a virtuous process that enables scientists to capitalise on the research made at academic level. By providing a wider and dynamic account of the early stages of biopharmaceutical innovation, we raise questions such as whether downstream returns are appropriately shared between the public and private sectors. These questions encourage future researchers and policymakers to further investigate this topic and apply fixes to the innovation process.

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Appendix

Table 1: Examples of identification of career trajectory.

Academic trajectory: *scientists who after their training (as PhD, MD or comparable levels), had spent most their careers working for academic institutions or public research institutes.*

"Professor James Lorens is the co-founder of BerGenBio, serves as the company's Senior Scientific Advisor and is also a Professor at the Department of Biomedicine at the University of Bergen. On completing his postdoctoral research studies at Stanford University he joined Rigel Inc., a San Francisco based biotechnology company, as a founding scientist and research director. He returned to UiB as a Professor in the Medical Faculty, starting his academic laboratory in the Dept. Biomedicine in 2004 to focus on cancer research. Prof. Lorens is a principal investigator at the Center for Cancer Biomarkers, Norwegian Center of Excellence." *Source: https://www.bergenbio.com/wp-content/uploads/2020/02/Prospectus-26-February-2020-BerGenBio-ASA.pdf*

"Prof. Riedemann received his medical training at Freiburg, Germany, and Stanford University, USA. He performed basic science research at The University of Michigan in the field of complement immunology and inflammation for several years and then completed his board certification in General Surgery at Hannover Medical School, where he still holds a Professorship in Experimental Surgery." *Source: https://www.inflarx.de/Home/About-Inflarx/Management.html*

Industrial trajectory: *scientists who after their training (as PhD, MD or comparable levels), had spent most of their careers working for private companies.*

"Dr Love was a senior scientist at Ciba Geigy/Novartis focused on novel drug delivery technologies and involved in the development of the world's leading eye-care pharmaceutical, Visudyne. In 1997, Dr Love founded Destiny Pharma and he is the co-inventor of the XF drug platform. Dr Love was a founding member of the BEAM Alliance, an EU SME group focused on promoting antimicrobial drug development [...]" – Ph.D. in Drug Delivery University of Wales." *Source: https://www.destinypharma.com/leadership/*

"After gaining a PhD in pharmacology from the University of Dijon, Philippe Genne began his scientific career as a project leader at Debiopharm where he oversaw a clinical development program related to multi-drug resistance inhibitors. He also worked as a research associate at Glaxo-Welcome." – PhD in pharmacology from the University of Dijon. *Source: https://oncodesign.com/en/about-oncodesign/management*

Mixed trajectory: *scientists who after their training (as PhD, MD or comparable levels) held positions in academia (such as post-doctoral research positions, lecturers etc.) as well as in the industry.*

"Pascale Fouqueray joined Merck KGaA in 2000 from Paris VII University, where she was Assistant Professor of physiology. At Merck KGaA, Dr. Fouqueray's activities were centered on metabolism, with a particular focus on diabetes and obesity but also including lipids and uric acid metabolism. Dr. Fouqueray was responsible for the clinical development of compounds for the treatment of diabetes and gout disease, working on strategies to define and reach proof-of-concept and investigate mechanisms of action."– PhD from the University of Paris XI. *Source: https://www.crunchbase.com/person/pascale-fouqueray*

"Daniel Obrecht, Ph.D., spent 11 years at the Central Research Laboratories of Roche Basel. In his previous position he was Head of the Combinatorial Chemistry Group. Dr. Daniel Obrecht obtained his Ph.D. in Chemistry from the University of Zurich in 1985 under the supervision of Prof. H. Heimgartner, after which he was associated with Prof. R. E. Ireland at Caltech as a postdoctoral fellow for 2 years." *Source: https://www.polyphor.com/about/*

Table 2: Correlation matrix.

		Inventor Professional Trajectory	Number of previous patents	Number of previous publications	Applicability	Backward citations	Forward citations	Number of assignees	Number of inventors	NPL citations
Inventor professional Trajectory	Pearson Correlation	1	0.017	-0.053	.133**	-0.062	-0.060	-.113**	-0.031	-.092**
	Sig. (2-tailed)		0.597	0.127	0.000	0.059	0.069	0.001	0.345	0.005
Number of previous patents	Pearson Correlation	0.017	1	.093**	0.036	.121**	-0.024	.132**	.217**	0.052
	Sig. (2-tailed)	0.597		0.007	0.293	0.000	0.465	0.000	0.000	0.114
Number of previous publications	Pearson Correlation	-0.053	.093**	1	.136**	-0.010	-.095**	.094**	-0.022	-0.007
	Sig. (2-tailed)	0.127	0.007		0.000	0.781	0.006	0.006	0.525	0.850
Applicability	Pearson Correlation	.133**	0.036	.136**	1	0.024	-0.035	-.079*	-0.040	-0.023
	Sig. (2-tailed)	0.000	0.293	0.000		0.491	0.310	0.022	0.250	0.506
Backward citations	Pearson Correlation	-0.062	.121**	-0.010	0.024	1	.287**	0.048	0.039	.692**
	Sig. (2-tailed)	0.059	0.000	0.781	0.491		0.000	0.140	0.232	0.000
Forward citations	Pearson Correlation	-0.060	-0.024	-.095**	-0.035	.287**	1	-0.047	-0.032	.287**
	Sig. (2-tailed)	0.069	0.465	0.006	0.310	0.000		0.152	0.327	0.000
Number of assignees	Pearson Correlation	-.113**	.132**	.094**	-.079*	0.048	-0.047	1	.127**	0.030
	Sig. (2-tailed)	0.001	0.000	0.006	0.022	0.140	0.152		0.000	0.361
Number of inventors	Pearson Correlation	-0.031	.217**	-0.022	-0.040	0.039	-0.032	.127**	1	0.047
	Sig. (2-tailed)	0.345	0.000	0.525	0.250	0.232	0.327	0.000		0.151
NPL citations	Pearson Correlation	-.092**	0.052	-0.007	-0.023	.692**	.287**	0.030	0.047	1
	Sig. (2-tailed)	0.005	0.114	0.850	0.506	0.000	0.000	0.361	0.151	