University patenting and the quest for technology transfer policy models in Europe

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Abstract

European universities have gradually taken a more aggressive stance towards IP appropriation. The policies behind these changes have been largely inspired in a linear model of university knowledge transfer and emulations of the US Bayh Dole Act. Our aim in this chapter is to highlight the heterogeneity of university technology transfer across European countries and the differences with respect to US universities, and describe the impact of policy changes, such as the abolition of the professor's privilege, in the light of new data and evidence. We challenge the linear model of university technology transfer and show how complex the relations between the actors involved can be, as well as the role that patents play in those relations.

Keywords: University patents; Patent quality; Technology transfer; Patent Ownerhsip; Professor's privilege; Europe.

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1. Introduction

In the same way as patents filed by firms are used as indicators of their innovation potential, patents held by universities have been increasingly used over the years by funding agencies and policy makers as a proxy for their ability to obtain returns from the knowledge created with public funds. Such an approach is implicitly based on a linear model of innovation, which states that innovation begins with basic research, continues with applied research and development, and ends with production and diffusion (Godin, 2006). However, this model has been criticized on many fronts. First, not all research disciplines are equally likely to have patents. Second, only a few university patents are licensed and only a few such patents generate relevant economic returns. Finally, informal interactions with university researchers have been found to be a much more important source for innovation than patent licensing in industry (Cohen et al., 2002). More importantly, university-industry collaborations are often solicited by industry rather than based on top-down licensing agreements and university inventions are frequently funded by a mix of public and private funds (Kline, 1985; Kline and Rosenberg, 1986). However, despite the caveats, the number of patents filed by universities continues to be a very popular indicator in the debates on the performance of universities and the accountability of publicly funded research.

European universities have been gradually both pressured into and given the resources of taking a more aggressive attitude towards IP appropriation. The European Commission explicitly recommended universities to create "coherent portfolios of intellectual property" (European Commission, 2008[1]; Arundel et al., 20135). Multiple government and institutional policy initiatives have promoted this trend over the years. Most of them initiated with the aim to emulate the success of the US model, which in Europe (and beyond) was mainly identified with the Bayh-Dole Act approved in 1980, and the underlying premise that universities should own the patents stemming from publicly funded research to then be able to license them, possibly on an exclusive basis, to industry.

The technological success of the United States in the past thirty years has often been attributed to inventions produced and owned by US universities that were later transferred to industry, thus implicitly assuming a linear model of university technology transfer. Policy makers and university administrators outside the US have tried to follow the same path by establishing technology transfer offices (TTOs) at universities and encouraging university faculty to disclose their inventions to them. In this context, it is generally assumed that when professors make a discovery which they believe has some application potential, they disclose it to their university TTO, which retains the IPR and operates the transfer in the form of licenses to companies seeking to commercialize university inventions (Siegel et al., 2003; Siegel et al., 2004).

The commercialization of university generated-inventions (beyond publicly funded research) has been assumed to necessarily involve three types of actors: inventors, TTOs and industry, in that order. However, as we argue in this chapter, widespread evidence shows that this sequence does not tell the whole story about university technology transfer. The linear path inventor-TTO-industry is only part of the picture of what happens in the market for technology.[2]

Our objective in this chapter is threefold: to highlight the complexity and heterogeneity of university technology transfer; to describe the main policy changes that have affected patenting activity at European universities in the past decades; and, lastly, to explain the effect that those changes have

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[1] http://ec.europa.eu/invest-in-research/pdf/ip_recommendation_en.pdf

[2] For an interesting analysis of shortcomings of the traditional linear model of technology transfer, see Litan et al. (2008) and Bradley et al. (2013).

had on university patenting, and academic patenting more broadly, in the light of new data and evidence.

The rest of the chapter is organized as follows. In section 2, we challenge the linear model of university technology transfer that has inspired most European policies in the past decades to show how complex the relations between the actors involved can be, as well as the role that patents play in those relations. In section 3, we analyze how the linear model relates to the US Bayh-Dole Act and we study the evolution of 'university patenting' in Europe in the light policy changes inspired in it. In section 4, we review the most recent empirical evidence on the true extent of 'academic patenting'. We recall that academic patenting is a much broader concept than university patenting, as it encompasses all patents invented by university professors, regardless of who owns them, and thus covers also patents owned by industry but invented by academic inventors. We show that, despite the increasing importance of university patenting in most European countries over the years, academic patenting is still of considerable size. In Section 5, we report evidence on the effect of changes in university IP regimes, such as the abolition of the professor's privilege, which seem to have mainly shifted ownership from industry and individuals to public institutions and increased the patenting propensity of European universities. Section 6 concludes with some policy recommendations.

2. Challenging the linear model of university technology transfer

As part of the linear model of innovation, the linear model of university technology transfer may be summarized as follows. It begins with a scientific discovery where the key actor is a university scientist who receives her salary and, possibly, a research grant by the State/Government. When the results of her research have some market potential, the scientist starts the technology transfer process and her institution (usually through the TTO) seeks some ways to turn her invention into a viable innovation by licensing it to industry.

Given this view, a number of market failures can stop the process short of reaching its final step (commercialization), such as information asymmetries between the researcher and the market or too high fixed transaction costs. As specialized intermediary structures that manage the transfer of technology between the suppliers of new knowledge (the scientist) and potential buyers (the firms), TTOs are set up to solve these issues.

Scientists normally do not recognize the potential uses of their discoveries nor do they know what firms may be potentially interested in acquiring their inventions. The TTOs intervene to reduce this gap between science and the market (Hellmann, 2007). Their role is to facilitate commercial knowledge transfers mainly through the licensing of inventions resulting from university research to industry (Siegel et al., 2004). According to the linear model, once the invention is disclosed, the TTO evaluates the invention and determines whether to pursue intellectual property protection and negotiate contracts with potential licensees

European universities have gradually taken a more aggressive stance towards IP appropriation. The policies behind these changes have been largely inspired in a linear model of university knowledge transfer and emulations of the US Bayh Dole Act. Our aim in this chapter is to highlight the heterogeneity of university technology transfer across European countries and the differences with respect to US universities, and describe the impact of policy changes, such as the abolition of the professor's privilege, in the light of new data and evidence. We challenge the linear model of university technology transfer and show how complex the relations between the actors involved can be, as well as the role that patents play in those relations.

In such a model the role of *industry*, or more generally the private sector, is confined only to the development phase. Operating in the market, firms wait to be contacted by the TTO and evaluate the inventions proposed. Then, if any agreement is reached, they adapt the university invention for commercial use.

The linear model of university technology transfer has been successful for its simplicity and for having given relevance to the necessity for intermediation in the market for technology. However, this model, by delimiting technology transfer to a predetermined path, simplifies in excess the complexities of this process. The university TTO[3], the inventor, and the private investors all bring know-how and resources essential to the innovation enterprise and relationships between them are largely governed by formal and informal contracts (Etzkowitz, 1998; Yeh, 2012).

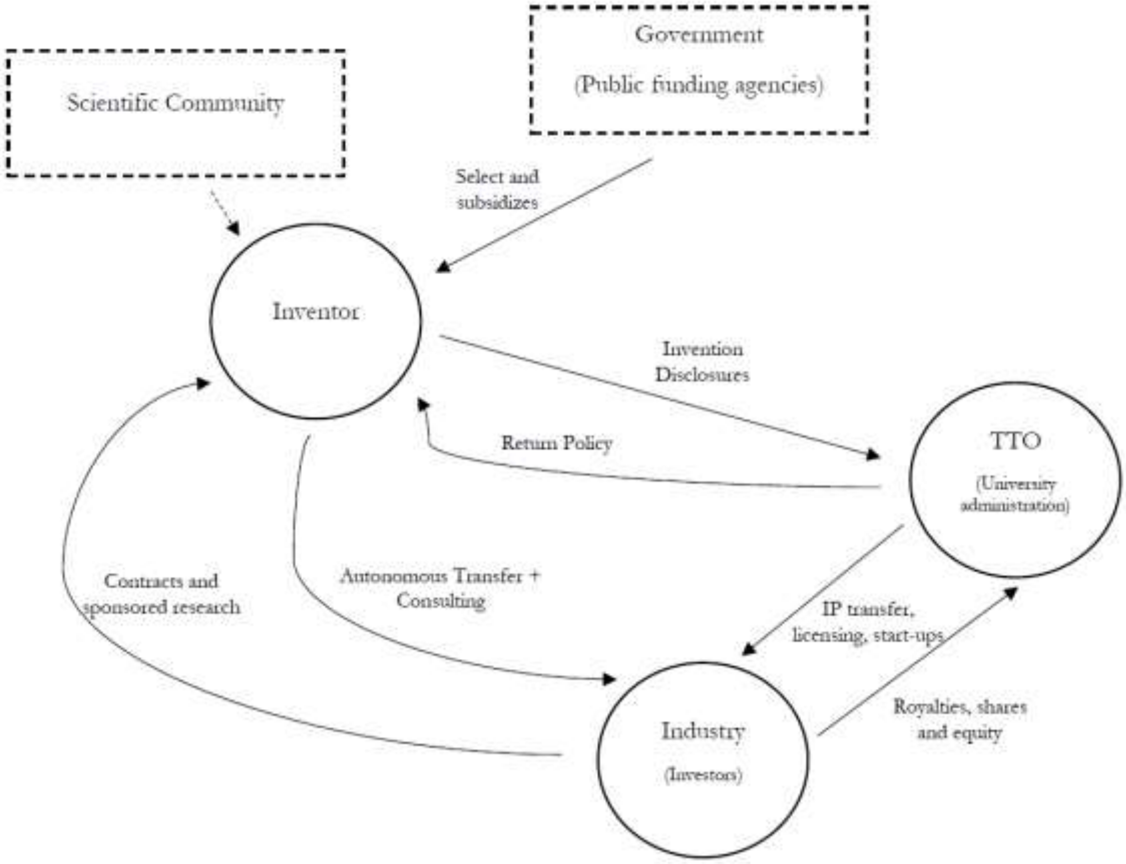
Three main criticisms of the linear model have been highlighted.

1. External environmental factors – such as the market demand and the sources of funding – are not fully taken into account and are limited to the development phase (Bradley et al., 2013). Moreover, the role played by reciprocal relationships between university, industry and government is minimized (Etzkowitz, 2003a).
2. Differences in technology transfer across disciplines are not accurately represented and the role in technology transfers of patents is overestimated, by forcing all disclosures to follow the same traditional path (Geuna and Muscio, 2009).
3. Alternative mechanisms of commercialization of university inventions are not taken into account. Academic inventions can in fact result from activities taking place at the sole initiative of the academic scientist and/or her university or in partnership with industry, in the forms of joint research, development partnership, or consulting (Colyvas et al., 2002; Czarnitzki et al., 2009; Lissoni, 2010; Thursby et al., 2009; Carayol and Sterzi, 2018). They may also be the direct result of fundamental research, as it was the case with early laser technology, polypropylene, and recombinant DNA (Hughes, 2011; Martin, 2007; Townes, 1999), or the complement of if, as for the case of scientific instruments (Von Hippel, 2007).

The complex relations between the inventor, the TTO and the industry in the technology transfer process are summarized in Figure 1. Differently from the linear model of university technology transfer, this alternative view does not necessarily begin with a publicly funded scientific discovery. Industry-sponsored research and research contracts to solve practical problems may be closely linked to public funds to support more fundamental research and their outcomes are often intertwined. Moreover, the role of TTO is also extended to negotiating contracts and sponsored research between the inventor and industry. The relationships involving the different actors in the technology transfer are circular.

[3] Some papers (see for example Jensen et al., 2003) consider the university administration and the TTO as two different and competing agents in the university technology transfer process. However, since normally the TTO is under the control of the university administration (as it is not the case of the faculty) and, in some cases (especially in Europe), universities lack of a formal TTO, we do not explicitly consider the role played by the university administration.

Figure 1. Main actors and the complexity of university technology transfer



Source: Own elaboration, based on Bradley et al. (2013)

The role of industry

According to the linear model of university technology transfer, results from basic research sometimes are the premises for improvements of enormous commercial significance. However, with the growth of science-based industry, universities and the basic research that they develop are strongly dependent on inputs from industry (Blaug et al., 2004).

Industry is not limited to the development phase, but plays two additional roles that are substantially missing in the conceptual framework implicit in the linear model of university technology transfer model: it funds university research and participates actively to the discovery process.

Over the past thirty years, universities have experienced an explosion in privately funded research and recent data show that firms are funding exploratory research, sometimes alone and sometimes along with public institutions.[4] Recent data available both for US and for Europe show that corporate-sponsored research is not only a widespread phenomenon but also extremely valuable for further innovation (Wright et al., 2014).[5] In some fields, first of all biotechnology, the most successful

[4] OECD (2010) shows that the share of industry funded academic research has grown in all countries since 1980.

[5] Wright et al (2014) reports that corporate-sponsored inventions of the University of California are licensed and cited more often than inventions generated only with federal grants.

university-industry interactions result in discoveries being licensed to industry in exchange for receiving funding upfront.

In general, either industry initiates a partnership with a university laboratory to solve a practical problem or the university laboratory gets in contact with industry to obtain complementary or additional funds for research.

In the first case, firms are carriers of commercial and societal needs (Etzkowitz, 2003b). It happens when firms look for the solution to a specific problem and select the most competent scientist (or laboratory). In most of the cases, this partnership regards applied research or consultancy, rather than fundamental research (Poyago-Theotoky et al., 2002). The professor's visibility and reputation are the criteria normally used for the selection of this type of partnership (Joly and Mangematin, 1996). Moreover, by initiating a partnership with a university, firms might also want to investigate areas outside their core business and select projects to fund in the hope of finding profit opportunities (Evans, 2010). This is the case, for example, of the $500-million research grant that British Petroleum gave in 2007 to the Berkeley-led consortium[6] in order to develop new sources of energy and reduce the impact of energy consumption (Wright et al., 2014). Or, ten years before, of the $25-million contract on GMO research signed by Novartis with the biological department of UC Berkeley.

In the second case, universities have their specific research interests but, because of shrinking budgets for research, need other sources of funding for financing their projects. This is the case of a $6-million donation made by Du Pont given to Harvard for the *Oncomouse* project held by professor Philip Leder in the early 1980s (Blaug et al., 2004). Heinzl et al. (2008) refer to these partnerships as research contracts in which university and industry define the R&D efforts to be performed. These contracts might include fundamental research, experiments, and consulting.

Of course, in both cases, the parties often negotiate IP ownership (or, the exclusive license on the invention) before the scientific discovery is achieved and the role of the TTO is limited to supervise and take care of legal aspects.

The role of inventors

According to the linear model of university technology transfer the role of the university scientists is limited to the inventive step: they make a discovery and then they disclose it to the TTO. However, academic inventors have two more important roles in the technology transfer: (1) they may help firms to develop the invention and (2) they may directly transfer the invention.

As regards as the first role, the inventor's involvement in the development stage is crucial for the companies, since most academic inventions are still at an embryonic stage and require further development efforts from their inventors.[7] For this reason, firms often ask the professor to continue to help them developing the technology and to maintain the licensing agreement. Braunerhjelm and Svensson (2010), using data on Swedish patents granted to individuals and small firms, find that the profits for a certain technology licensed to an established firm are higher when the inventor is involved in the commercialization process. Agrawal (2006) finds that engaging the inventor in licensing agreements increases the likelihood and degree of commercialization success of university inventions. Involvement of the inventor in the commercialization process facilitates the transfer of

[6] Partnership with Lawrence Berkeley National Laboratory (LBNL) and the University of Illinois at Urbana-Champaign

[7] According to a 1996 survey of US universities, 45% of the inventions licensed were only a proof of concept and 37% no more than a lab scale prototype (Thursby et al., 2001).

latent knowledge, defined as knowledge that is not-codified but codifiable, such as lessons learned from 'failed experiments'.

The effort of the faculty in the development phase is in most of the cases not observable and not contractible ex ante so that it is difficult to commit to the transfer of this expertise and know-how, especially when professors prefer research to development (Jensen et al., 2003, Dechenaux et al., 2009). This situation leads to a moral hazard problem with the consequence of sub-optimal investments. For this reason, one of the primary role of TTO is to help inventors and firms to negotiate and draw up contracts that involve payments linked, when possible, to observable revenues generated by the licensed invention. By compensating the inventor for the supplementary effort in the development phase, these payments give to the inventors the incentives to exert (more) effort in the transfer process. These payments may take the form of royalties which, normally, are expressed as shares of the licensee's revenues.

As regards as the second role, contrary to the linear model, inventors may transfer the inventions without the help of the TTO. Inventors may consider to bypass the TTO and go for informal mechanisms of technology transfer (Kenney and Patton, 2009; Kumar, 2010; Carayol and Sterzi, 2018): these phenomena are relatively common in Europe and to a lesser extent also in the US (Thursby et al., 2009; Lissoni et al., 2008; Crespi et al., 2010; Sterzi, 2013; Lissoni et al., 2013; Schoen and Buenstorf, 2013; Maraut and Martinez, 2014; Sterzi et al., 2018). These alternative mechanisms of technology transfer are discussed in the next Section.

The role of the TTO

In the linear model of university technology transfer the TTO has the primary role of providing organizational solutions for coordination failures in the market for university technologies. These activities require considerable time, effort and competences, which justify the presence of the TTO as an institution characterized by a lower opportunity cost of time and better specialization than the professors (Chukumba and Jensen, 2005).

When professors notify the TTO of their discoveries they might also delegate to the university all rights to negotiate licenses on their behalf (Litan et al., 2008). However, TTOs may initially screen inventions and retain only some of them. Since most universities have limited budgets for filing patents, the TTOs must be selective about which inventions to pursue and it may also happen that TTOs give back the IP to the faculty.[8] Furthermore, screening inventions does not only allow cutting costs but it is often a strategy for building reputation and so producing higher revenues: by pooling inventions across departments within a university, the TTO can shelve certain scientific discoveries in order to raise the licensee's beliefs about the expected value of the invention (Biglaiser, 1993; Lizzeri, 1999; Macho-Stadler et al., 2007).

Only after the screening process, the TTO decides to move a disclosure forward and starts the patent application process. From a theoretical point of view, the patent application encourages the faculty to disclose the invention and the TTO to actively search for a potential licensee since it protects the inventor (and his university) from the possibility that a firm can stole the invention. This ex-post[9] role played by patents is theoretically discussed in Hellmann (2007), in which the author formally shows how patent protection might facilitate technology transfer from university to the private sector by allowing scientists to delegate the promotion of their scientific discoveries to the TTO. During

[8] Note that in some countries the invention needs to be proposed and given back to the State.

[9] The ex-ante role of patents refers to the incentive argument, according to which patents give a guarantee that the intellectual property generated by the investment is adequately protected against appropriation.

this phase, the TTO has to carry the cost of patenting which goes from the basic fees for patent offices[10] to legal fees which typically include the cost of conducting a patent search, preparing the patent application and filing it.[11]

With the conclusion of the patent application process, the TTO begins to search and identify potential firms that want to utilize the invention. Only after having identified firms potentially interested in the academic invention, the negotiation on licensing agreements begins. In this phase, especially when they grant exclusive licenses[12], TTOs normally behave as a profit-maximizer agent, interested in monetizing specific inventions rather than increasing overall social welfare. This behavior is particularly evident in the US where universities, in the last decades, not only started to enforce their patents, but also started to sell them to patent trolls[13] and, to a minor extent, also invest and have stakes in those companies.[14]

However, overall these activities produce modest revenues to the universities (Bulut and Moschini, 2006). Using the words of the presidents of Clemson University and Boston University[15] "most university technology-transfer operations do not receive enough royalties to offset their total operating costs" (Wall Street Journal, 2015, April 14).[16] Most inventions that individually have yielded in excess of $1 million of income to universities are in the pharmaceutical industry, one of heaviest users of the patent system (Merrill and Mazza, 2011). This is not surprising since in most other industries (such as electronics and software) firms normally use trade secrets and lead times in order to exploit their technological advantage (Levin et al., 1987; Orsenigo and Sterzi, 2010).

The linear model of university technology transfer considers alternatives to TTO disclosure and patenting outside the university only as marginal phenomena or as the result of free-riding behaviour that may undermine a TTO-center technology transfer model. However, these phenomena are relatively common in Europe and to a lesser extent also in the US (Thursby et al., 2009; Lissoni et al., 2008; Crespi et al., 2010; Sterzi, 2013; Lissoni et al., 2013; Schoen and Buenstorf, 2013; Maraut and Martinez, 2014; Sterzi et al., 2018).[17]

The existence of an idea does not assure that it will receive the attention needed for development (Roberts and Peters, 1981). According to a survey of US universities (Jensen et al., 2003), TTO managers in fact believe that in most cases faculty may prefer not to disclose their scientific discoveries to the point that less than half of the inventions with commercial potential are disclosed to their office.

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[10] Filing a PCT application costs approximately $4000. At the USPTO it is more than $3000 which includes basic filing fee, patents search fee, patent examination fee and issue fee. The EPO has similar costs.

[11] Attorney fees can easily arrive to thousands of dollars (Bradley et al. 2013).

[12] According Thursby and Thursby (2003) half of the licenses in the US are exclusive. However, the exclusivity of the license is not automatically a sign of high profits for the university. Some of the most lucrative academic patents in the US history were licensed very liberally. This is the case, for example, of the Cohen/Boyer patent (Feldman et al., 2005) and of the Axel patent (Colaianni and Cook-Deegan, 2009)

[13]Levy (2015), patent counsel at the Computer and Communications Industry Association, using data from Allied Security Trust, reports that US universities sell patents to patent trolls (patent assertion entities) 6 out of 10 times (http://www.patentprogress.org/2015/05/07/why-universities-oppose-real-patent-reform-money/).

[14] For example, University of Texas Investment Management Company (UTIMCO), an endowment arm of University of Texas, invested $75 million in Intellectual Ventures, a leading collector of patents whose business model focuses on buying patents and licensing them to third parties.

[15]http://www.wsj.com/articles/a-patent-troll-bill-with-bad-college-grades-1429051694?KEYWORDS=patent+troll

[16] However the Boston University sued Apple on a 20 year old patent and asked for a chunk of Apple's profits.

[17] See section 4 later for an overview of recent evidence on academic patenting showing that a large extent of academic patenting is not captured by university patenting statistics when patents are invented by academics but owned by industry.

Since scientists and TTO managers respond to different incentives and their goals are often not aligned, disclosure depends largely on the university's reward systems and culture (Debackere and Veugelers, 2005). When the university has an incentive structure that supports commercialization activities, the scientist is more likely to be aware of the available formal mechanisms of technology transfer and disclose.

The TTO could be more efficient at searching potential partners than professors but it faces information asymmetry vis-à-vis the two sides of the market[18]: about invention qualities, of which professors are better informed, and about the capacity of exploiting these ideas on which companies are themselves better informed. When information asymmetry problems are much more important than searching costs or when the TTO is inefficient (or even absent), we can observe a sort of "autonomous transfer" between the professor and the firm (Carayol and Sterzi, 2018).

The scientist in fact might perceive too many barriers and disadvantages to involving the TTO, so that he might consider to bypass it and go for informal mechanisms of technology transfer (Kenney and Patton, 2009; Kumar, 2010; Carayol and Sterzi, 2018). In many cases, empirical evidence shows that academic inventors patented their invention without the help of the university. Markman et al. (2008) for example survey academic inventors in US universities and find that 42% of them had already bypassed their TTO at least once.

The university administration may also observe this behavior over intellectual property rights and, when done without its agreement, exceptionally reacts by litigating with faculty researchers. This is the case, for example, of a legal controversy between the University of Missouri (MU) and Galen Suppes, professor of Chemistry at MU[19]. Suppes has been accused of breaking his employment agreement by secreting patent and invention information and failing to assign rights in some of his inventions. From the professor's perspective, the issue however is a systemic flaws in the University's technology transfer commercialization system. Suppes in fact, not only maintains his innocence[20], but also planned a counter-suit to draw attention to the underlying issue of MU's intellectual technology transfer office and its counterproductive practices.

Sometimes, this behavior is also unintentional as many researchers may simply be unaware of the TTO's existence. This typically happens more frequently in Europe, where most of the universities started to establish their TTO only during the '90s. As we will see later in section 3, around that time the European university system gradually started to put technology transfer at the center of its mission and adopted policies to increase patenting propensity and foster licensing to industry. Some countries moved away from inventor ownership (professor's privilege) towards different system of university-ownership (Bayh-Dole-like Acts) and, more generally, university researchers were increasingly asked to disclose all their potentially patentable inventions to the TTOs. However, this sometimes required a complete change of culture in many institutions. By using data on 3250 researchers in 24 European universities, Huyghe et al. (2016) found that, already in 2012-2013, only a minority of researchers were aware of the existence of a TTO at their university.

Professors may choose not to disclose to the TTO and opt for other transfer mechanisms for other reasons (Thursby and Thursby, 2002). When they are not able to appreciate the commercial potential

[18] In the literature on university technology transfer some papers do not consider any information asymmetry between the inventor and the TTO. They instead insist on the information asymmetry between the TTO and the potential firm interested in the technology on the value of the invention and propose the use of royalties as a way to signal the value of the innovation (Gallini and Wright, 1990; Macho-Stadler and Pérez-Castrillo, 1991).
[19] http://www.ipadvocatefoundation.org is a non-profit organization founded to help safeguards interests of faculty inventors. It reports six case studies of American universities litigating with faculty researchers over intellectual property rights. The Suppes' case study on IP ownership is available here: http://www.ipadvocatefoundation.org/studies/suppes/Suppes.pdf
[20] Dr. Galen J. Suppes made the discovery subject of the suit before he began working at MU.

of an invention, or when they are unwilling to spend time on applied R&D normally needed in licensing activities or, finally, when they believe that commercial activity is inappropriate for an academic (e.g. they prefer to publish and put their inventions in the public domain). So, before evaluating the quality of the inventions disclosed by researchers and search for potential licensees, the main task for the TTO is thus to facilitate the disclosure of academic inventions. In doing so, TTOs may work in two directions. First, they can establish an organizational culture that fosters technology transfer in order to educate and convince faculty to disclose their inventions (Bercovitz and Feldman, 2008; Lawson and Sterzi, 2014): there is evidence that the competences and the capabilities of the TTO do strongly influence faculty participation in the licensing activity (Colyvas et al., 2002). Second, they can define licensing contracts and university policies to persuade inventors to disclose their inventions and participate in the commercialization process (Macho-Stadler et al., 1996; Jensen and Thursby, 2001). In the same vein, Lach and Schankerman (2008) show that, in the US, universities giving a higher share of royalties to the inventor generate more inventions. However, Arqué-Castells et al. (2016) showed that this evidence is less pronounced in Spain and in Portugal, countries with a much smaller number of university inventions and less developed markets for technology, where only few inventors find royalty sharing to be highly influential.

3. IP regimes and the growth of university patenting

The emphasis on the linear model and the pressure on universities and their TTOs to file patents on faculty inventions (and obtain millions in royalty fees by licensing them to industry) is usually traced back to the Bayh-Dole Act, enacted in 1980 in the United States. The supporters of the Act believed that difficulties in patenting the outputs of federally funded research and in licensing the patents exclusively to industry limited university contributions to innovation, although such arguments generally lacked empirical evidence (Mowery and Sampat, 2005). Indeed, it has been claimed that the debate was mainly ideological. As argued by Rebecca Eisenberg (1996), with the approval of the Bayh-Dole Act, the US Congress endorsed a new vision of how best to get research results sponsored publicly utilized in the private sector: "In this new vision, public ownership of research results was equivalent to "dead-hand" control, and the public domain was a treacherous quicksand pit in which discoveries sink beyond reach of the private sector. If the results of federally-sponsored research were to be rescued from oblivion and successfully developed into commercial products, they would have to be patented and offered up for private appropriation."

University patenting in United States and the Bayh-Dole Act

The Bayh-Dole Act gave permission to small businesses and universities to file patents on results of government sponsored research and to provide exclusive licenses to third parties, and retained *march in rights* for the government (never exercised yet). In 1984, the provision was extended to large businesses (Eisenberg, 1996).[21] More precisely, as summarized by Loise and Stevens (2010), the Act stated that inventions made with federal funding could be owned by the institutions receiving the funds, who should also:

- Grant licenses rather than transfer ownership
- Disclose the government's interest in patent applications and notify the government before abandoning any patent application

[21] According to Henderson et al (1998), the 1984 passage of Public Law 98-620 expanded the rights of universities further by removing certain restrictions contained in the Bayh-Dole Act regarding the kinds of inventions that universities could own, and the rights of universities to assign their property rights to other parties.

- Share the income received with the inventors (how much to share was left up to individual institutions)
- Use any residual income retained by the institution for research and education
- Grant a royalty-free non-exclusive license to US Government for its own use
- Require licensees to manufacture products in the US that were to be sold in the US
- Give preference to small businesses

For the top US research universities with patenting experience, the permission to retain patent ownership introduced by the Bayh-Dole Act simply accelerated and facilitated the way things were already done, by "replacing a web of institutional patent agreements that had been negotiated between individual universities and federal agencies with a uniform policy, and it expressed support for the negotiation of exclusive licenses between universities and industrial firms" (Mowery and Sampat, 2005). For the rest of universities it represented a more radical change as it pointed at the potential role of patents as a source of additional revenues. New TTOs were created and new patent policies and incentives for university professors to disclose inventions established.

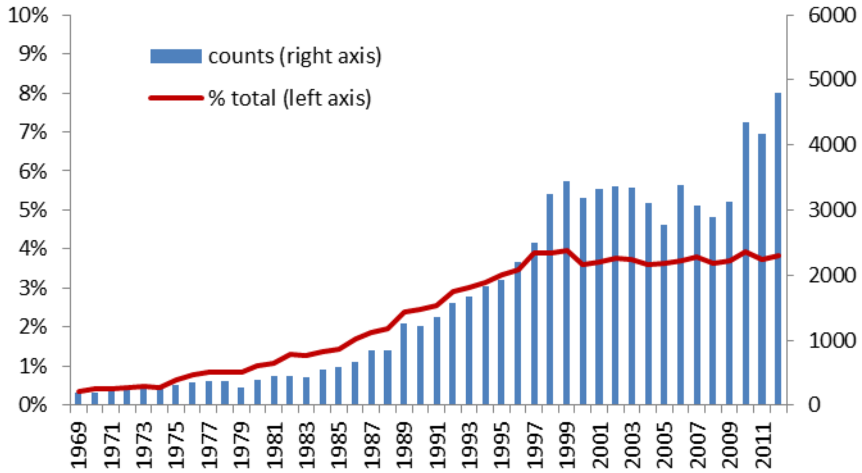
The growth of university patenting had started before 1980, but it increased more markedly after 1980 because of a combination of factors, where the Bayh-Dole Act was just one among many. Other factors included the increasing importance of the biotechnology and software sectors, which were emerging sectors at the time, the rise of industry applications based on biomedical research and a general trend towards strengthening intellectual property protection in the United States. The latter included the establishment of the US Court of Appeals for the Federal Circuit (CAFC) and was reflected in several pro-patent decisions expanding the patent subject matter in general and to cover inventions in biotechnology and software (Martínez and Guellec, 2004). The willingness to follow the example of a few successful universities was probably another factor influencing the increasing propensity to patent at universities. Florida, Wisconsin, Michigan State universities all had "blockbuster inventions that lifted them to new levels of financial success" (Foley, 2012). These changes not only increased patenting by experienced institutions, but also attracted many inexperienced universities in the patenting field with patents of lower technological importance and generality (Mowery and Ziedonis, 2000). The assumption of the Bayh-Dole Act was mainly that the percentage of university research that was of value to industry was large enough to justify the added costs of managing IP in this new way; and that universities, which had never been in the IP business, would learn how to do this and would do it well (Foley, 2012).

Figure 2 below presents evidence of the growth in university patent numbers. The share of US university-owned patents with respect to all patents grew steadily during the 1970s and 1980s until the mid-1990s, going from 0.4% in 1969 to 1.1% in 1981 and 2.5% in 1991, but seemed to reach a peak at the end of the 1990s at around 4% and remained around that level since then. In absolute terms, the rate of growth of the number of US university patents was exponential in the 1980s and 1990s, but slowed down in the 2000s. US universities went from having only 200 patents granted in 1970 to 400 in 1980 and now they have between 3000 and 4000 patents granted every year at USPTO.

The sheer growth in university patent numbers and the substantial licensing revenues obtained by some university blockbuster patents caught the attention of university administrators and policy makers outside United States. Critics argued that not all these new university patents were equally valuable and not all of them were licensed to industry and only a few were used as the basis to found academic spin-offs and start-ups. The pressure on university patenting also raised concerns about effects on other aspects of university research and the dynamics of university industry collaboration. Nonetheless, despite the warnings, the changes brought by the Bayh-Dole Act were mainly seen outside the US as a way to increase the attractiveness of European university inventions to industry and raise university revenues in a context of increasing funding constraints (with block grant funding being replaced by project funding). 'International emulations' of the Act started to proliferate (Mowery and Sampat, 2005).[22]

Figure 2. US university-owned patents as a share of all US owned patents

USPTO official data, grant years 1969-2012



Notes: Patents were identified as university owned based on the name of the first assignee.
Source: Own elaboration based on USPTO official data from
https://www.uspto.gov/web/offices/ac/ido/oeip/taf/univ/asgn/table_1_2012.htm

European institutional differences and heterogeneous university IP regimes

The legislation governing patent ownership of publicly funded inventions was quite heterogeneous in Europe at the time of the changes in the US (Damsgaard and Thursby, 2013; Greenbaum and Scott, 2010; Grimaldi et al., 2011; Kenney and Patton, 2011; Mowery and Sampat, 2005; Schacht, 2012; Valentin and Jensen, 2007; von Proff et al., 2012; Sterzi, 2013; Sterzi et al., 2018).

Germany, Austria and the Nordic countries (Denmark, Norway, Sweden and Finland) had exceptions to IP laws allowing university researchers to retain the ownership of the inventions developed at their institutions, thanks to the so-called Professor's privilege. All of them, except Sweden, abolished such privilege after 2000. In other countries, such as United Kingdom[23], Spain, France and Switzerland, university employees were treated as any other employee, and their inventions belonged to their institutions. The emphasis in these countries was to encourage commercialization and technology transfer as one important mission of universities, a stance that was reflected in a number of laws, policy changes, university statutes and guidelines. However, the degree to which this kind of measures could have an influence largely depended on the legislation affecting universities' autonomy when it came to asset management and recruitment of IP experts (Baldini et al., 2006; Della Malva et al., 2013; Geuna and Rossi, 2011).

In Germany, the change was motivated by a concern among policymakers that individual researchers might be unwilling or unable to pursue commercial application of their ideas through patenting or

[22] The influence of the Act was also felt in other parts of the world, both in developed countries like Japan (Takenaka, 2005) and in emerging countries like Malaysia, South Africa or Philippines (Zuniga, 2011).
[23] An exception in the UK was the University of Cambridge that till 2001 did not enforce fully the university ownership right (Geuna and Rossi, 2011).

licensing activity. Italy went against the tide when it introduced the professor's privilege in 2001 and the opposite argument was used. Individual inventors would be better placed to profit from their discoveries, since universities lacked the competence and culture to commercialize inventions (Geuna and Rossi, 2011). Nonetheless, as argued by Lissoni et al. (2013), the increasing autonomy gained by Italian universities since the end of the 1980s left the measure with almost no effect.[24] A change introduced in 2005, narrowing down the privilege to inventions fully funded with intramural university funds reduced the influence of the Italian Professor's privilege even further. Table 1 summarises the trend towards institutional ownership in Europe that started at the end of the 1990s, with the notable exceptions of Sweden and Italy (Geuna and Rossi, 2011; Chardonnens, 2010).

Table 1. Changes in IP regimes for academic patenting in a selection of European countries in the 1990s and 2000s

Policy and legal changes	Country	Change	Trend
Abolishment of the Professor's privilege to increase scientists' incentives to disclose inventions to universities	Denmark	2000	Universities would assign a share of the patent licensing revenue to the inventor and pay all the costs associated with the patent application
	Germany	2002	
	Austria	2002	
	Norway	2003	
	Finland	2007	
Stronger enforcement of institutional ownership system already in place	United Kingdom	1977	Harmonisation, measures to encourage IPR awareness, commercialisation and creation of technology transfer offices
	Spain	1986	
	France	1999	
	Switzerland	1991	
	Belgium	1997	
Introduction of Professor's privilege (from institutional ownership to inventor ownership)	Italy	2001	Only applies to inventions fully funded by the university employing the inventor since 2005
Continuation of the Professor's privilege	Sweden	1949	Recurrent national debate about IP regimes, that always concludes in the lack of need for a legal change

Source: Own elaboration based on information from Geuna and Rossi (2011) for most countries; Chardonnens (2010) for Switzerland; Della Malva et al. (2013) for France and Mejer (2011) for Belgium (the change applied in 1997 in the Flemish region and in 1998 for the French Community).

One aspect that is seldom stressed when commenting the changes introduced by the Bayh-Dole Act in the US is that they 'only' applied to inventions developed with federal funds. These represented the majority of university research funding in most countries (about 70% or more in the US at the time)[25] but the Act did not have any ruling on university inventions stemming from private funds. The 2011 Supreme Court decision on *Stanford v Roche* recalls that inventors remain the *ab initio* owners of federally funded inventions, and "the Bayh Dole Act only comes to the picture after the contractor, in this case Stanford, receives the invention via assignment under ordinary contract law" (Yeh, 2012). When the assignment is not clearly attributed, ownership remains with the inventor. The consequence of this decision has led to strengthening university employment contracts to ensure that employee inventions are clearly assigned to the institution, so that Bayh-Dole can apply.

The distinction by source of funds was not an issue in the emulations of Bayh-Dole Act adopted in Europe. In Germany, for instance, in the same way as the Professor's privilege applied to all

[24] The university autonomy rules introduced in 1988-89 in Italy clarified institutional ownership and they represented a real change, not so much the introduction of the professor's privilege in 2001 (Lissoni et al., 2013).

[25] As reported in Henderson et al (1998), US industry funding of university research increased from 2.6% in 1970 to 3.9% in 1980 and 7.1% in 1994. With federal funding at 60 to 70% of the total, the remainder is funded by state and local governments and institutions' own funds.

inventions performed by university professors, regardless of whether they were publicly or privately funded, the question was whether its abolition meant that all inventions obtained by university employees belonged to their universities. A note published by a German patent law firm argued that "shortly after the establishment of this new regulation, the industry felt unsafe about any inventions being the result of any collaboration with universities and the possibility of exclusively exploiting them. On the other hand, the universities wanted to obtain fair royalties from the industry for any inventions constituting a result going beyond the ordinary research activities."[26] The situation has been generally solved, the same law firm argues, by using carefully drafted contracts stipulating the obligations of the industry and the university in case of service or works contracts, contracted research and research cooperation. In countries where there had never been a professor's privilege, like Spain, the law also allows industry to retain the ownership of inventions developed by public researchers in the context of research collaboration or as part of research contracts (Azagra-Caro, 2011; Martinez et al., 2013; Maraut and Martinez, 2014).

The IP regime was only one of the factors influencing patenting and licensing differences between the US and Europe. The institutional context of university patenting in Europe was also generally very different to the United States. To start with, in Europe there was little competition among universities, most of them lacked administrative and financial autonomy and researchers had the status of civil servants in many countries (e.g. Spain, France, Italy). In contrast, as noted by Mowery and Sampat (2005), the US higher education system had no centralized administrative control; it encouraged considerable inter-institutional competition (for students, faculty, resources and prestige); had a long tradition of research collaborations with industry, including much more than patenting and licensing, and much of the research performed focused on scientific problems with industrial applications. Moreover, by the late 1970s many US universities had established their own patent policies and technology transfer offices.

Trends in European university patenting

A combination of all the factors just mentioned explain the difference in the volume and growth rates experienced by university patenting in different European countries, as shown in Figures 3 and 4 below. In general, the share of university patenting has grown over the years in most countries, except possibly Sweden, where there has been no policy change. This may be taken as a rough indication of a positive response of European universities to the increasing pressure to patent but countries differ widely in the level of university patenting in absolute and relative figures. Whereas in the US, universities hold about 4% of all US patents granted every year since the end of the 1990s the situation is quite varied in Europe. France has recently reached 4%, Germany stabilized at around 2% after the abolition of the professor's privilege (from less than 1% before), UK has 8% and growing, and in Finland and Sweden patenting at EPO is negligible (well below 1%), to cite a few of the countries shown in the graphs.

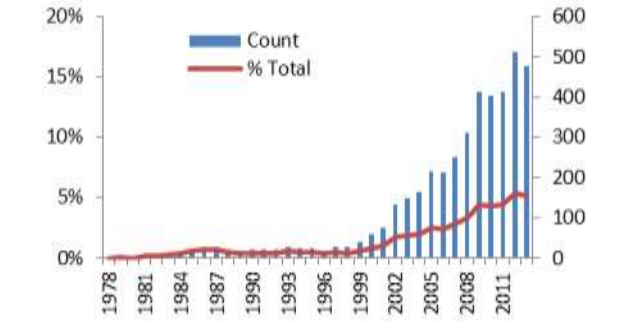
[26] http://www.vossiusandpartner.com/pdf/pdf_23.pdf

Figure 3. EPO patent filings by European universities in selected countries

EPO applications from PATSTAT, filing years 1978-2013

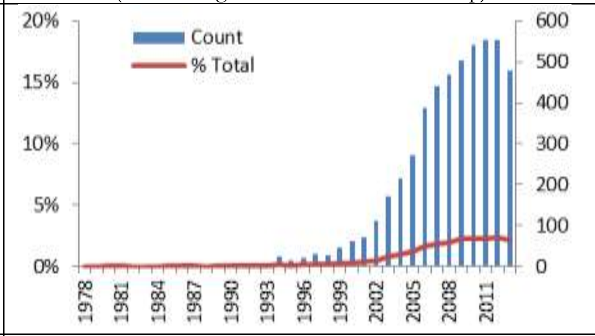
France

(since 1999 encouragement of institutional enforcement)



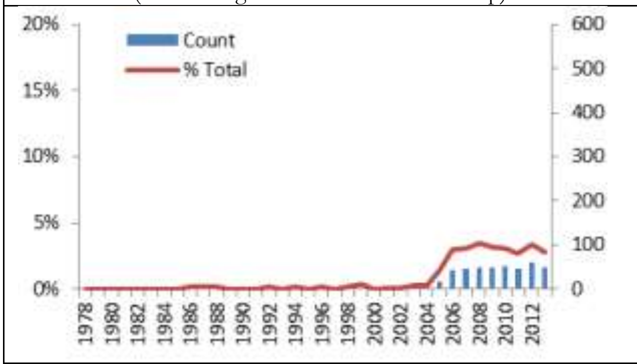
Germany

(2002 change to institutional ownership)



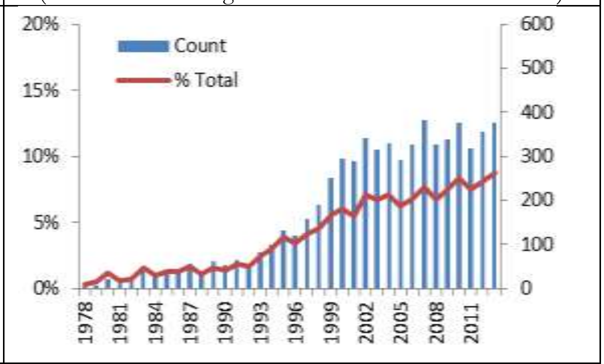
Austria

(2002 change to institutional ownership)



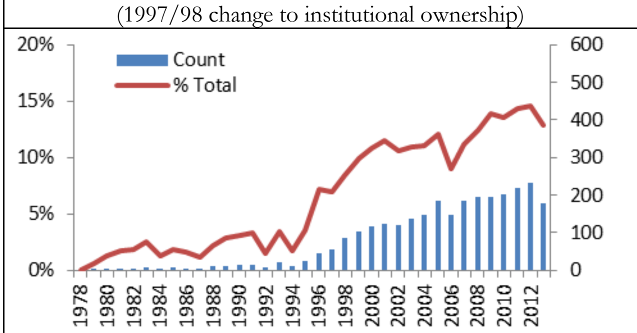
United Kingdom

(since 1977 encouragement of institutional enforcement)



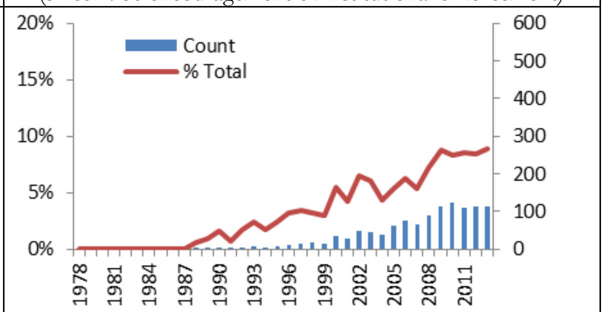
Belgium

(1997/98 change to institutional ownership)



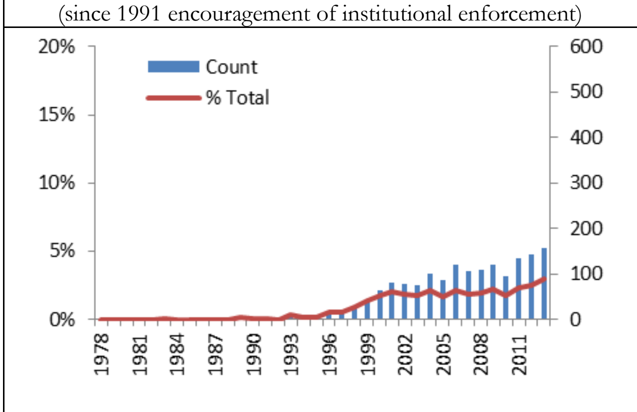
Spain

(since 1986 encouragement of institutional enforcement)



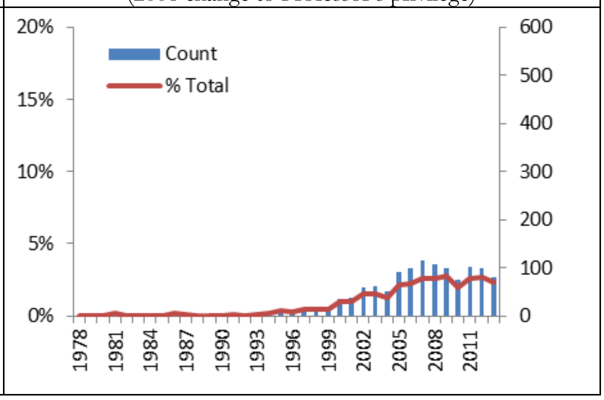
Switzerland

(since 1991 encouragement of institutional enforcement)



Italy

(2001 change to Professor's privilege)

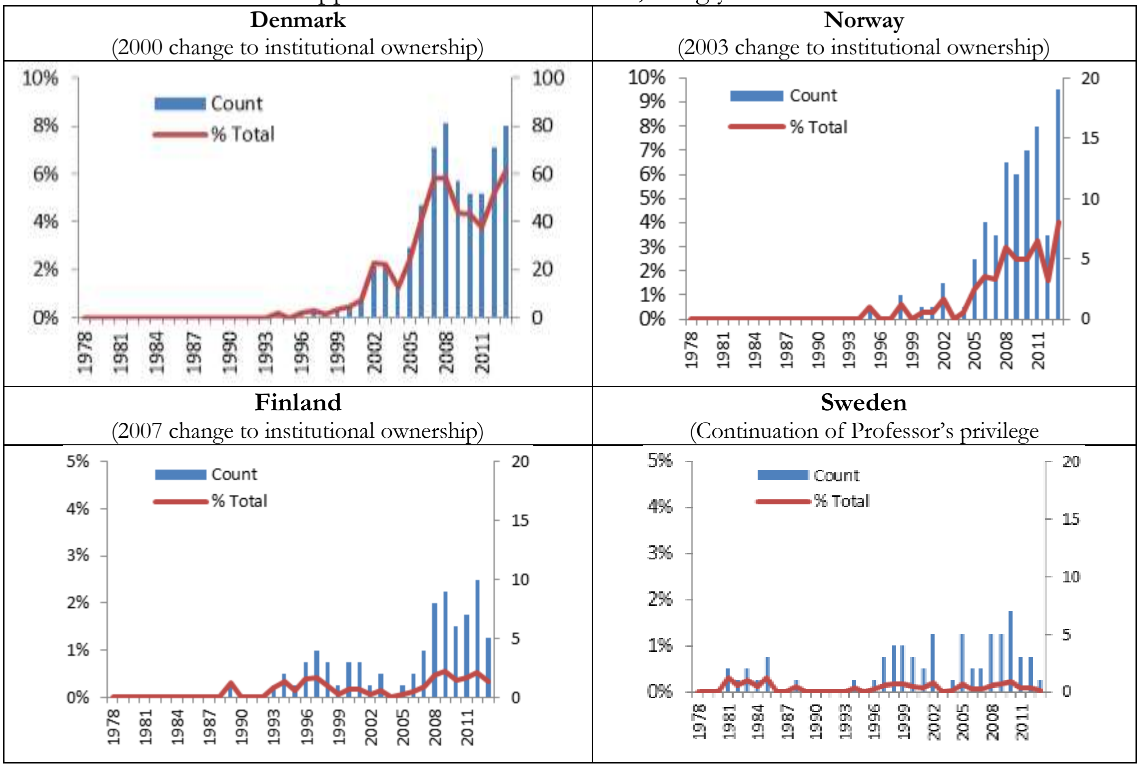


Note: Full counting. All EPO patent filings with at least one university applicant included in the 'Count' of university patent applications. The total number of patent filings used to calculate '% Total' is the number of EPO patent applications filed by residents from the same country (filings having only foreign applicants are not included in the denominator).

Source: Own elaboration based on data from PATSTAT April 2016 and EEE-PAT October 2015 (Callaert et al., 2011).

Figure 4. EPO patent filings by European universities in the Nordic countries

EPO applications from PATSTAT, filing years 1978-2013



Note: Full counting. All EPO patent filings with at least one university applicant included in the 'Count' of university patent applications. The total number of patent filings used to calculate '% Total' is the number of EPO patent applications filed by residents from the same country (filings having only foreign applicants are not included in the denominator). Note the different scale in the axis for Denmark, and for all Nordic countries with respect to Figure 4.

Source: Own elaboration based on data from PATSTAT April 2016 and EEE-PAT October 2015 (Callaert et al., 2011).

Whether this general growth has been caused by the policy changes remains an open question (see Section 5 later). On the one hand, policy changes have probably led European universities to put more effort to retain title of the inventions developed by their faculty. On the other hand, the growth in university patenting might have been mostly caused by the entry of new institutions in the system (i.e. universities that were not patenting before and file lower quality patents precisely because of their lack of experience), and by increasing patenting opportunities in scientific research with industrial applications (notably in biotechnology) (Henderson et al., 1998).

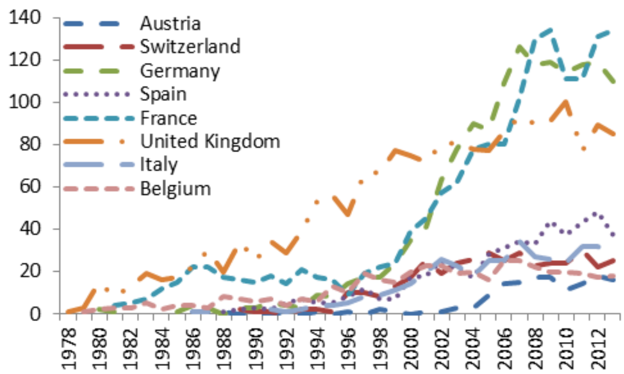
Figure 5 shows that there has been indeed an increase in the number of universities filing patents at EPO in the past years. This might have been caused by the creation of new institutions or, most importantly, by patenting by institutions which had not patented before. The increase is very steep for Germany and France at the end of the 1990s, predating in both cases the beginning of their respective policy changes. In turn, UK shows a continuous increase over the years, as well as Spain, Switzerland and Italy, which suggests that the increase may be only partly related to higher propensity to patent by old institutions and mostly due to the creation of new ones altogether.[27]

[27] It may also be possibly due to imperfections in the harmonization of university names in the OECD HAN database caused by the proliferation of new institutions.

In turn, Figure 6 confirms for the three top countries (Germany, UK and France) that university patenting growth has been mainly due to patenting in the field of biomedical research, as it was the case for the United States in the 1990s.

Figure 5. Number of universities with EPO patent applications, by country and filing year

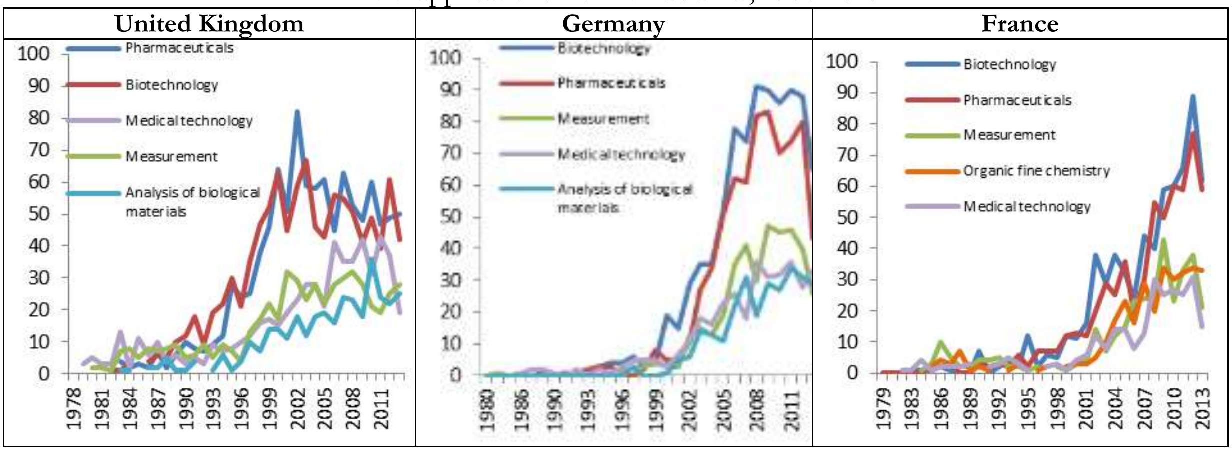
EPO applications from PATSTAT, 1978-2013



Note: Count of distinct han_id from the OECD HAN database of PATSTAT identified as 'universities' as in the EEE-PAT database.
Source: Own elaboration based on data from OECD HAN included in PATSTAT April 2016 and EEE-PAT October 2015 (Callaert et al., 2011).

Figure 6. University EPO patent applications in top 5 technology fields per country and filing year, United Kingdom, Germany, and France

EPO applications from PATSTAT, 1978-2013



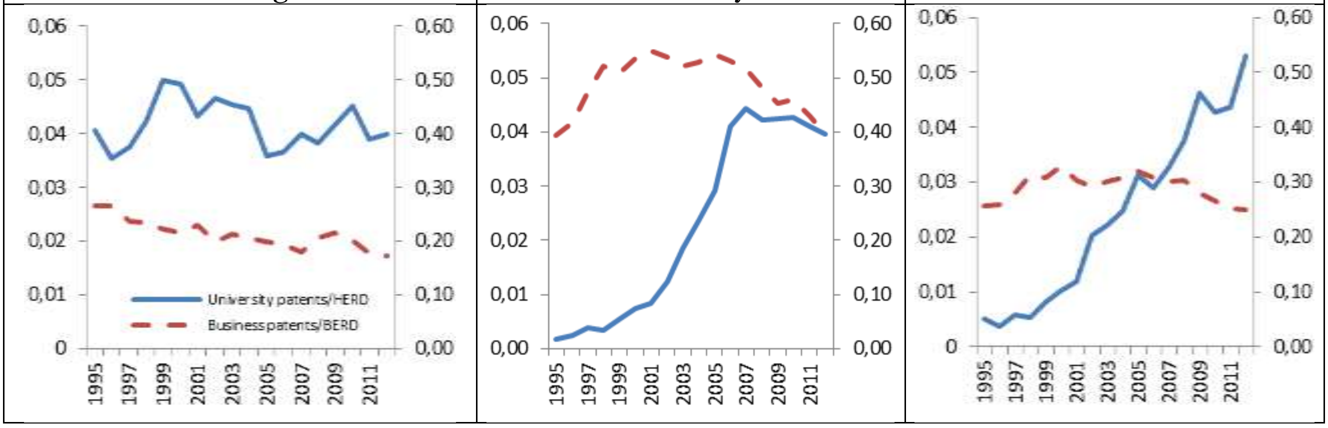
Note: Full counting. All EPO patent filings with at least one university applicant included in the count of university patent applications.
Source: Own elaboration based on data from PATSTAT April 2016, EEE-PAT October 2015 (Callaert et al., 2011) and the 35 technology fields from WIPO correspondence (Schmoch, 2008).

Figure 7 shows that the university propensity to patent in the top three countries, measured as the ratio of university owned patents over university spending in R&D, has leveled around 4-5% in the last years. The fact that in Germany the propensity to patent in the business sector (particularly in the chemical, automotive and electronic sectors) is much higher than in the UK and France may be explained by the differences in the use of patents across sectors. The chemical industry has been traditionally strong in Germany, since the second half of the 1800s, and chemicals, along with pharmaceuticals, are the sectors for which patent protection is considered essential.

Figure 7. Patent filings over investment in R&D: United Kingdom, Germany, and France

EPO applications from PATSTAT, Business R&D (BERD), Higher Education R&D (HERD), 1995-2012

United Kingdom	Germany	France



Note: Full counting. All EPO patent filings with at least one university applicant included in the count of university patent applications, and all EPO filings with at least one business applicant included in the count of business patents. Left y-axis for university patents-HERD ratio and right y-axis for business patents-BERD.
Source: Own elaboration based on data from PATSTAT April 2016, EEE-PAT October 2015 (Callaert et al., 2011) and Eurostat for BERD and GERD in Million Euros current prices (http://appsso.eurostat.ec.europa.eu/nui)

Finally, Figure 8 and 9 display the evolution of industry and university owned patents in Europe in terms of originality and quality between 1995 and 2012 for the top five technological fields considered in Figure 6. The patent originality index was first proposed by Henderson, Trajtenberg and Jaffe in 1998 in an attempt to quantify two key characteristics of patents. The originality index measures the breadth of "the technological roots of the underlying research" of a given patent (Henderson et al., 1998). The patent quality or technological importance of a patent is measured by the number of citations received from other patents counted over a period of five years after the publication date. Thus, the originality index is backward looking and patent quality is forward looking.

The data on the originality index and patent quality displayed in Figure 8 and 9 for industry and university owned European university patent applications come from the OECD Patent Quality Indicators database (Squicciarini et al., 2013). The originality index ranges from 0 to 1. A higher value of the originality index suggests that a given patent relies on (cites) a larger number of diverse sources and may thus be more 'innovative'. A large number of citations received is indicator of technological and, to some extent, economic importance of the patent (Lanjouw and Schankerman, 2004; Harhoff et al., 1999; Harhoff and Reitzig, 2004; Jaffe et al., 2000; Hirschey and Richardson, 2004; Fischer and Leidinger, 2014; Jaffe and De Rassenfosse 2017).

Figure 8 displays patent average values for originality and quality at EPO for the two groups of business and university owned patents. The descriptive evidence suggests that university patents are on average more original than industry patents but that this difference is narrowing since the end of the '90s. University patents are significantly more original than industry patents in the '90s, when the difference is between 0.06 and 0.07, rather than after 2000, when this difference decreases to an interval between 0.01 and 0.04. Concerning the technological quality, measured by the number of 5-year forward citations, patents owned by universities seem to be constantly of lower quality than those owned by business entities. The decrease in quality from 2008, both for business and university patents, is an artefactual mechanism due to the citation lag.

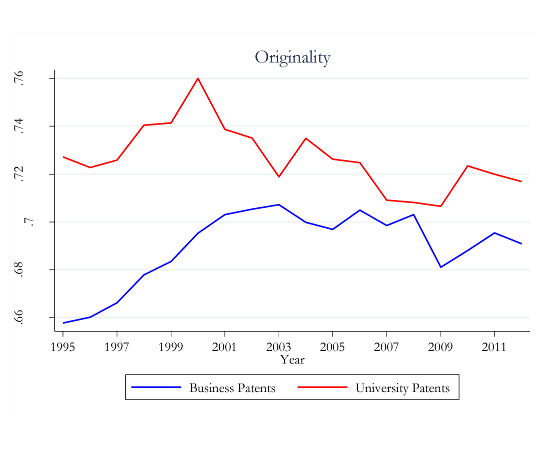
The decrease in the originality index and the difference in patent quality might be in part explained by the fact that universities started (or increased) to patent in technological fields possibly less original or less important. To control for this sectoral heterogeneity, Figure 9 and Figure 10 show the average values for originality and quality for two main fields in which universities are particularly active: Chemistry (Pharmaceuticals and Biotechnology) and Instruments (Measurement, Analysis of biological materials, Medical technology).

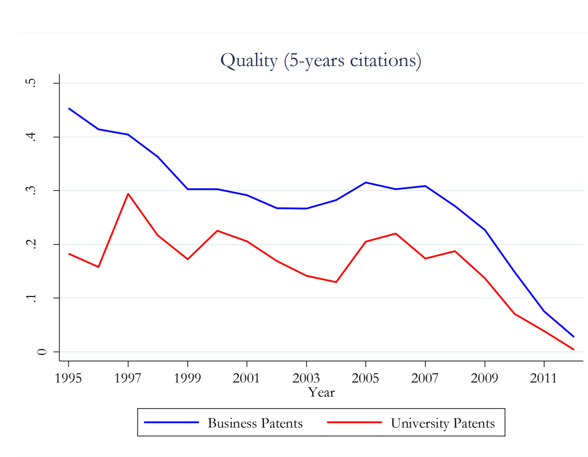
When we restrict the observations to patents in the field of Pharmaceuticals and Biotechnology (Figure 9), university patents results on average less original than business patents, with this difference that increases over time, starting from the early 2000s, time when many of the legal reforms about the university IP regime took place in Europe. After that, industry patents continue their increasing trend in terms of originality, whereas university patents start to be less and less original – probably protecting more marginal improvements, mimicking industry patents in being more specific – and the gap between both groups widens.

Results for Instruments (Figure 10) are in line with simple average values shown in Figure 8. University patents are more original than business patents, with the difference that, however, decreases over time.

These figures are overall consistent with the early finding of Henderson et al. (1998) about the decrease in generality of university patents after the Bayh-Dole Act, which had been for some time more general than the average patent in their random control sample but by the end of the 1980s the difference had disappeared. They concluded that the increase in university patenting observed in the US in the 1980s was a result of a higher propensity to patent, and also led to more technology transfer to industry, but it did not necessarily translate in a similar increase in the number of important inventions.

Figure 8. European patents generality and originality by type of owner, 1995-2012

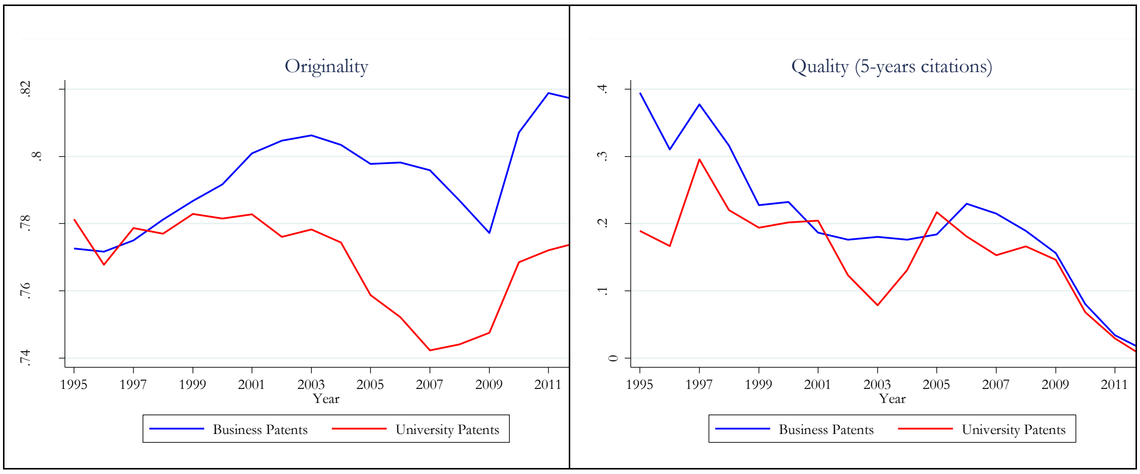




Note: The initial sample is restricted to EPO patent applications having at least one university or industry applicant. For the breakdown between university and industry owned patents we apply full counting. All EPO patent filings with at least one university applicant included in the count of university owned patent applications, and all EPO patent filings with no university applicant included in the count of industry owned patent applications. Only patent filings in the top 5 technology fields are retained for the analysis (i.e. Biotechnology, Pharmaceuticals, Measurement, Analysis of biological materials, Medical technology), as regards country of residence of applicants, the following have been retained: Austria, Belgium, Switzerland, Germany, Spain, Finland, Denmark, France, United Kingdom, Ireland, Italy, Norway, Sweden and the Netherlands.

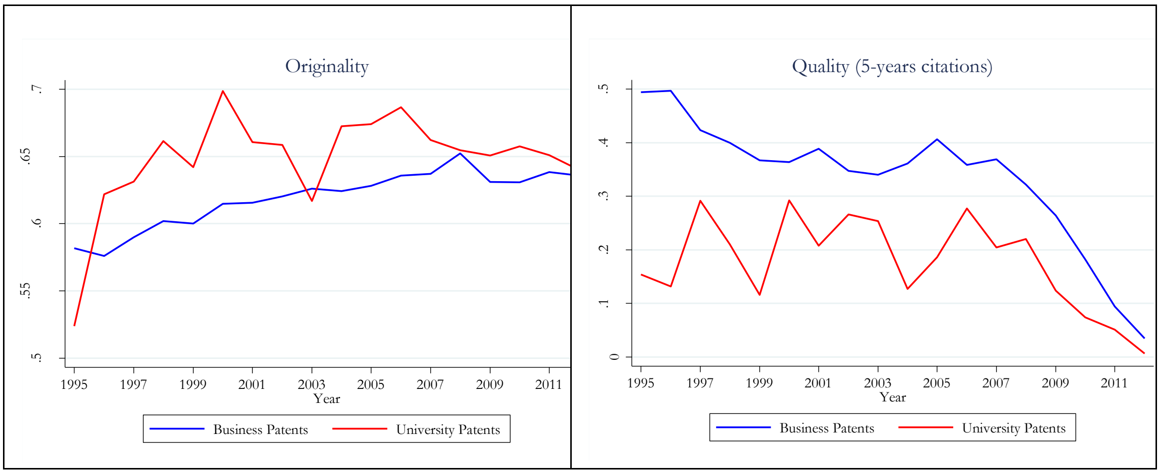
Source: Own elaboration based on patent data from PATSTAT April 2016, sectoral classification of applicants from EEE-PAT October 2015 (Callaert et al., 2011) and technology field classification of patents from WIPO correspondence (Schmoch, 2008). Data on the patent generality and the patent originality index from the OECD Patent Quality Indicators Database, version October 2015 (Squicciarini et al., 2013).

Figure 9. European patents generality and originality by type of owner, 1995-2012 Biotechnology and Pharmaceuticals



Note: See Figure 8 for a description of the sample construction. Own elaboration based on data from PATSTAT April 2016, EEE-PAT October 2015 (Callaert et al., 2011) and the 35 technology fields from WIPO correspondence (Schmoch, 2008).

Figure 10. European patents generality and originality by type of owner, 1995-2012 Measurement, Analysis of biological materials, Medical technology



Note: See Figure 8 for a description of the sample construction. Own elaboration based on data from PATSTAT April 2016, EEE-PAT October 2015 (Callaert et al., 2011) and the 35 technology fields from WIPO correspondence (Schmoch, 2008).

4. The true extent of academic patenting in Europe

The 'European paradox' was a term coined in EC documents and policy fora in the 1990s[28]. It stated that one of the main problems for European policy was to translate the results from scientific research to industrial applications because European researchers performed very well in terms of scientific publications, but lagged behind in terms of patenting and commercialization of research results, compared with the United States and Japan. Even though, as provocatively argued by Dosi et al. (2006), "the paradox mostly appears just in the flourishing business of reporting to and by the European Commission itself rather than in the data", it was behind an increasing policy pressure on universities to patent which gave fruits as we saw earlier. What they suggested was that the gap between Europe and United States was not limited to technology transfer or patenting, but rather that Europe was lagging behind also in the relative number of publications per researcher and their impact, and that much of the problem of the apparently low level of technology transfer was due to the low investment in R&D in industry. On the other hand, looking at university patents only was not the best way to estimate the full potential of technology transfer in terms of university patents: many other channels were used, formal and informal (Perkmann et al., 2013) and among the formal ones, not taking into account that contract research and consulting often leads to patents invented by academics but owned by industry was an important limitation.

In this context, a new perspective was brought along chiefly by European economists, aiming to discover the real breadth and scope of academic scientists' inventive activity going well beyond the patents filed by universities in their own name ("university patents") to estimate the number of patents listing them as inventors ("academic patents"). Identifying the sector of the inventor required substantial effort and matching inventor names with information available elsewhere, such as staff lists or publication databases.

A number of pioneer studies from different European countries estimated the number of patents invented by 'academic inventors' up to the first half of the 2000s: Meyer et al. (2003) on Finland; Meyer et al. (2005) comparing Finland and the Flemish region of Belgium; Balconi et al. (2004) on Italy; Iversen et al. (2007) on Norway; Saragossi and van Pottelsberghe (2003) on Belgium; Becher et al. (1996), Schmiemann and Durvy (2003), Schmoch (2007), Czarnitzki et al. (2007) on Germany; Wallmark (1997) on Chalmers university in Sweden; Sterzi (2013) on UK; Lissoni et al. (2008) on France, Italy and Sweeden; Azagra-Caro et al. (2006) on Strasbourg university in France; and, finally, Crespi et al. (2007) on the sample patents included in the PatVal survey in six European countries.

All of them confirmed that official statistics had been underestimating the contribution of academic researchers to patenting by taking as the reference the identity of the applicant, rather than that of the inventor. Whereas inventions developed by university professors but not owned by universities accounted for about 25% of all university inventions in the US (Thursby et al., 2009), these studies revealed that the share was much higher in Europe, on average 60% (Lissoni, 2013). Some of these studies were carried out as part of the 2004-2008 EU-funded KEINS project, which aimed, among other things, to gather evidence on academic patenting for France, Italy, Sweden, Netherlands, Denmark, and the UK for the period 1978-2004 (e.g. Lissoni et al., 2008; Banal-Estañol et al., 2010; Sterzi, 2013). Although the information included in the database was mainly cross-sectional, it showed that academic patents had grown from 2% of total domestic EPO patent applications of France, Italy, and Sweden in 1985, to around 4% in 2000 (Lissoni et al., 2008). The proportion of academic patents had doubled in fifteen years, and the growth had been more marked in biotechnology and pharmaceuticals.

[28] More precisely in the 1995 EC Green Paper on Innovation (Dosi et al., 2006).

Building on previous evidence, another EU-wide initiative to gather comparable data on academic patenting was the APE-INV programme, funded by the European Science Foundation (ESF). The programme run between 2009 and 2013 with the goal to support coordination activities of researchers from different European countries interested in creating large scale databases on academic patenting in their respective countries following comparable and transparent methodologies. It enabled to update and further exploit data for some of the countries which had already been included in KEINS, such as Italy, Sweden, UK, France (Lissoni et al., 2013; Bourelos et al., 2012; Ljungberg et al., 2013; Lawson, 2013; Cassi and Wane, 2013) added new countries to the endeavor, notably Belgium, Spain, Germany and Austria (Callaert et al., 2013; Mejer, 2011; Martinez et al., 2013; Maraut and Martinez, 2014; Schoen and Buenstorf, 2013; Schoen et al., 2014; Stummer et al., 2013). Results confirmed earlier findings.[29] Furthermore, the programme demonstrated that although the general conclusions about the size and growth of academic patenting did not change, more fine grained findings were sensitive to the use of different methods and data sources, and that precision and recall rates improved substantially thanks to the use of complex record linkage and natural language processing techniques to match and disambiguate large volumes of data (Raffo and Lhuillery, 2009; Maraut and Martinez, 2014; Pezzoni et al., 2014; Schoen et al., 2014).

Oher studies carried out recently and having similar aims include: i) Ejermo and Kallstrom (2016) for Sweden, who match EPO inventors from Sweden with social security numbers to then match them to employer-employee information to distinguish between industry and university employees; ii) von Proff et al. (2012) and Czarnitzki et al. (2012) for Germany, who identified German academic inventors in the inventor lists from their title (e.g. Prof. Dr.) using the technique first applied by Becher et al. (1996);[30] and finally iii) Dornbusch et al. (2012) who match authors and inventors in Germany (similarly to Maraut and Martinez, 2014 for Spain).

In sum, available evidence from different European country studies and at different points in time consistently point at an underestimation of the extent of university invented patents when only university owned patents are considered. In one of the early studies, Crespi et al. (2010) argued that "once the data are corrected to take account of the different ownership structures in Europe and the USA, a back-of-the-envelope calculation suggests that the European academic system produces about the same share of total patenting in Europe as US universities do in the USA. Thus, the appearance of a lack of university patents in Europe is due to a lack of university-owned patents, not a lack of university-invented patents." The different works listed above confirmed that such rough calculation was quite accurate. However, the challenge remains to study the evolution of academic patenting over time, with databases being the result of on one-off exercises due to the considerable amount of work required to identify academic inventors each time (e.g. gathering professors or academic authors' lists, matching their names to inventors, disambiguating homonyms, etc.).

5. The impact of IP ownership on European academic invention

The newly available data on academic patenting just described has enabled to address two questions regarding the quality of academic patenting in Europe: i) whether university owned patents are of

[29] For more information, visit the ESF APE-INV Project website at: www.ape-inv.eu . The journal *Industry and Innovation* published a special issue with studies developed during the project, available at https://www.tandfonline.com/toc/ciai20/20/5?nav=tocList

[30] And only valid in Germany and possibly Austria too, given the high propensity of German university professors to include their title as part of their name, a tradition that is seldom followed in other European countries.

lower or higher quality than industry-owned academic patents; and ii) whether changes in IP regimes have had an effect on the quantity and importance of academic patenting. [31]

As regards the first question, several studies have compared industry-owned academic patents to university-owned patents in terms of quality and commercial value, but findings depend on the country analyzed. The different features of academic systems, in particular the degree of autonomy at the institutional and researcher level, seem to have a strong influence on the selection of inventions owned by the academic institution and owned by industry. Lissoni and Montobbio (2015) compare the value and impact of academic patents with different types of owners across five European countries (Denmark, France, Italy, the Netherlands and Sweden) and find that industry owned academic patents tend to be more cited than academic patents owned by universities. However, when looking at individual countries, the cross-country result holds for Denmark and Italy but not for the Netherlands, where academic patents (regardless of their ownership) are always more cited than industry patents. Callaert et al. (2013) find evidence consistent with the Netherlands in the Flemish region in Belgium, whereas Czarnitzki et al. (2012) or Schoen and Buenstorf (2013) find results consistent with the cross-country evidence for Germany. As regards the UK, Sterzi (2013) observes that although industry owned academic patents are indeed more cited in the first years from publication than university owned ones, the difference diminishes over time and even disappears when considering later citations.

The second question has been mostly looked at by analyzing academic patenting before and after the abolishment of the Professor's privilege in Norway, Denmark, Germany and Finland. Four countries where the policy change provides a *natural experiment* to researchers interested in assessing the impact of different IP regimes. But it has also been addressed for Italy, where the Professor's privilege was introduced rather than abolished, and for France, where there was no radical legal change affecting ownership as in the previous countries, but a law was enacted in 1999 aiming to change the way university administration regarded IP. As put by Lissoni et al. (2008), in all these countries, one way of assessing the impact of the change of IP regimes, would be "to verify whether any increase in the number of patents filed by universities is due to a growth in inventive activity by academic scientists, or simply due to a property shift".

A small number of studies, summarized below, have aimed to analyze the impact of the IP regime changes in European countries with more or less sophisticated evaluation methods, all of them relying on information at the researcher level, rather than the institution level. To the best of our knowledge, only these studies have addressed the question due to the complexity of the analysis and the scarcity of longitudinal data on academic patenting (i.e. due to lack of time series of academic staff lists and the complexity involved in matching them to patent inventor lists) (see Table A1 in the Annex for a brief description of their sources and findings).

Evidence for **Norway** is found in two descriptive studies (Iversen et al., 2007 and Spilling et al., 2015) and a recent econometric paper (Hvide and Jones, 2018). First, Iversen et al. (2007) present a descriptive analysis of the trend in Norwegian patent applications where they distinguish between those invented by researchers affiliated to Norwegian universities and to public research institutes. In the first study of 2007, which only covers patent filings between 1998 and 2003, they observe a decrease of university patenting in 2003, but they argue it is temporary and attribute it to lack of experience and uncertainty in face of the change. They also note that "the conception of 'professor

[31] In this section we focus on the impact of policy changes affecting IP ownership of academic inventions in Europe only, but there are other papers analyzing the impact of the IP regime shift brought by the Bayh-Dole Act in the US, such as Damsgaard and Thursby (2013), Rosell and Agrawal (2009), Henderson et al (1998), Mowery et al (2004), to cite a few.

privilege' patents as predominantly single-inventor patents held by the researcher himself tends to be inaccurate in most sectors. Individual public sector research inventor patents are in fact relatively limited." As a follow up to the 2007 study, Spilling et al. (2015) show that the share of Norwegian patent filings invented by Norwegian public sector researchers fell slightly (about 1%) between 1999-2003 and 2004-2008, but they warn against attributing it to the policy change as the overall economic and climate patenting changed greatly during the period in Norway. Finally, Hvide and Jones (2016) carry out multiple Difference-in-Difference regression, comparing patents and start-ups of university researchers with those of researchers working outside universities (public research institutes, companies, etc.) where they include a number of controls (year, technology, demographics). They consistently find an approximate 50% decline in the rate of new venture creation and patenting by university researchers after the reform, as well as a decline in the quality of university start-ups and patents. The drastic decline found in the econometric analysis performed by Hvide and Jones (2018) contrasts with the slight reduction observed in the data gathered by Spilling et al. (2015), but they use different methodologies, and their data is not fully comparable. Hvide and Jones(2018) analyse and report changes in the 'rate of patenting', which is calculated as patents per 'worker' (i.e. academic employees), whereas Spilling et al. (2015) focus on the share of 'researcher patents' as share of all domestic patent applications and find that the intensity of researcher patents remains relatively stable at least in domestic applications. As Hvide and Jones (2018) observe, the number of Norwegian university researchers rose relatively rapidly over the 1995- 2010 period. The fact that the numerator (number of academic employees) grows very quickly during the period is a major explanation for the fall in the "rate of patenting" found in their study. Both studies highlight the difficulties involved in this kind of research and their different methodologies and results call for further research to conclude about the definitive size of the impact of the law change.

For **Denmark**, Valentin and Jensen (2007) use data form the Scanbit Database from the Research Centre on Biotech Business at Copenhagen Business School, which includes patent information and other indicators on drug discovery of dedicated biotechnology firms in Denmark, Sweden and Norway. They take profit of the fact that Sweden has not changed its IP regime, whereas Denmark did change it in 2000, and perform Difference-in-Difference regressions to compare biotech patenting involving Danish and Swedish domestic academic inventors. They find significant reductions in contributions from Danish domestic academic inventors, combined with a simultaneous substitutive increase of non-Danish academic inventors and a moderate increase in academic inventions channeled into university owned-patents after the policy change. They argue that the reduction in Danish academic patenting can at least be partly attributed to the reform. In their own words, "the larger part of the inventive potential of academia, previously mobilised into company-owned patents, seems to have been rendered inactive as a result of the reform". In their opinion, the ex-ante allocation of IPR to the universities requested after the reform mostly harmed exploratory research, where results are still uncertain at the time when research collaboration contracts are signed and allocation of potential future outputs have to be discussed. The specificity of the sample, focused on patents filed by biotech firms with and without academic inventors listed, means that the database is biased towards joint industry-university exploratory research, which may explain the clear negative impact of the law, as argued by the authors. It remains to be seen whether the same can be found for patents invented by university researchers in other fields, or even in biotechnology, but owned by other institutions, different from dedicated biotech firms. As for Norway, further research on the impact of this law change in Denmark is needed. Lissoni et al. (2009) show that a considerable amount of Danish patenting activity shifted from professors to universities following the abolition and the large majority of academic inventions were owned by business companies both before and after the abolition of the privilege

Germany is the country for which more studies have been carried out and more diverse methodologies have been applied to identify academic inventors, as well as the country with the highest volume of university patents in Europe in the past decades (See Figure 3 earlier). However, before 2002, German policy makers were worried because only about 4% of all German patents were invented in German universities (Czarnitziki et al., 2015). As argued by von Proff et al. (2012), "In contrast to the U.S., the German suspicion was not that university inventions might be shelved because IPR negotiations between university administrations and federal agencies were obstructed by red tape. Rather, German policy makers were concerned that individual researchers might be unwilling or unable to pursue the commercial application of their ideas through patenting and licensing activities. Dedicated technology transfer offices (TTOs) were seen as better suited to fulfill these tasks, and accordingly the change in the legal treatment of university inventions was complemented by substantial federal subsidies for newly established TTOs". The rationale for the change was therefore similar to that in Norway and Denmark. The academic system in Germany is completely decentralized, and the division between universities and public research organisations applied as in Norway, in addition to the differences between East and West Germany before the reunification: the privilege had never applied to researchers in German public research organisations (e.g. Fraunhofer Gesselschaft, Max Planck) or in former East German universities (von Proff et al., 2012). Analysing the impact of the change thus requires taking this heterogeneity into account in addition to gathering large volumes of patent data where to identify which ones are invented by university professors and which not, before and after 2002. Schmoch (2007), von Proff et al. (2012) and Czarnitizki et al. (2015 and 2016) take as the point of departure the German tradition of professors to sign all documents with their title. Czarnitzki et al. (2015) initially search for the terms "Prof." and "Dr." in patent databases to then enlarge the initial samples iteratively with homonyms to finally apply a disambiguation strategy. Alternatively, Schoen and Buenstorf (2013) match university calendars to inventor names and Dornbusch et al. (2012) match names of scientific authors to inventors.

As regards the analysis of the impact of the policy change, there does not seem to be consensus among scholars. Schmoch (2007) observe no evidence of a change with a descriptive analysis of trends in numbers of academic invented patents before and after the abolition of the privilege. Von Proff et al. (2012) apply econometric estimations and find no evidence of a change either, but observe growth in university owned patents, which makes them conclude that the reform mainly caused a shift in ownership rights to the universities. In turn, interestingly, the descriptive evidence provided by Dornbusch et al. (2012) points at a different trend of German and EPO patent filings invented by German professors: whereas EPO academic invented filings, which are likely to be considered of higher expected value by applicants, increased after the change, the academic invented filings to the German patent office decreased. Finally, Czarnitzki et al. (2015) uses patents invented by PRO researchers as a control group in a Difference-in-Difference estimation of the impact of the change to university invented patents, by collapsing German and EPO filings at the family level, and excluding patents filed by researchers with double affiliation PRO and university. They find that university invented patents decreased overall after the change, in line with Hvide and Jones (2018) for Norway. When they distinguish between different types of professors, they find that patenting by professors with previous industry connections decreased after the change and patenting by professors without connections increased, so they conclude that the latter benefited more from the institutionalization of technology transfer as they were the ones for whom not having the support of the university was relatively more costly.

Lastly, Ejermo and Toivanen (2018) study the effect of the abolishment of the professor's privilege in **Finland**, where the change was implemented much later, in 2007. They use a difference in difference regression, on a matched sample of employer-employee data at the individual level, to estimate the effect of the policy change on the number of patents invented by researchers working at universities compared to those invented in research institutes and firms. They find that patenting dropped at least 29% after 2007 in the country and 46% after 2004, which corresponds to the year of the announcement.

To summarise, as we argued earlier, the different results obtained, the restrictions imposed to build the samples and the different methodologies used to identify academic inventors, call for more comparative analyses before reaching a final conclusion. What seems clear is that the abolishment of the Professor's privilege in Germany in 2002 has not resulted in an increase in academic patenting. The change has either had no impact (and simply caused a property shift) or a negative impact, likely to be suffered mostly by those who were more active in patenting and had connections with industry prior to the greater involvement of TTOs. To the best of our knowledge, the issue of multiple affiliations has not yet been dealt with available studies which offers an interesting path for future research given that being affiliated both at a university and a PRO might be an indication of higher quality and researchers in that situation might have had the choice of using the professor's privilege or not, prior to the change.

The studies on the impact of policy changes on patents invented by university professors in France and Italy – based on patents identified by matching inventors to professors' lists – are different from the studies on Norway, Denmark, Germany and Finland just reviewed because they do not uniquely focus on the impact of specific legal changes. Instead, they consider the question of the impact of policy changes on academic patenting more broadly and highlight the importance of university autonomy and decentralized decision making (Della Malva et al., 2013, Lissoni et al., 2013). The latter is found to be more important than changes to the IP regime in the Italian study, for instance, as the professor's privilege was introduced in Italy in 2001.

For **France**, Della Malva et al. (2013) note that rather than a change in the IP regime of university inventions, which never benefited from an exception in the country, what might have really made a difference are: i) the transformation of the national science system experienced since the 1990s in the country, which included the 1999 Innovation Act (also known as "Loi Allegre" by the name of the Minister at the time); and ii) a decade long of prior changes leading to the creation of TTOs in French universities. The study concludes that the Innovation Act increased the probability for universities to retain property rights on inventions, and co-ownership with business companies increased as a result, but the opening of TTOs, which in many cases predated the Act, had a larger effect on such probability.

For **Italy**, Lissoni et al. (2013) find that the absolute number of Italian academic patents has increased, their weight on total patenting by domestic inventors has decreased, and the share of academic patents owned by universities has more than tripled. They conclude that the increased autonomy of Italian universities, which has allowed them to introduce explicit IP regulations concerning inventions made by their staff, has effectively neutralized the introduction of the professor privilege. This makes them suggest that "debating over the professor privilege may be less relevant than debating the use made by universities of their increasing autonomy, when it comes to IP matters. We are not yet in a position to evaluate the observed trends in terms of financial returns to universities, and impact on innovation levels in the country. That requires further data collection, which is under way."

The last sentence may apply to all studies reviewed in this section. There is still need for further data collection on the use of patents and their commercialization and on the services and products sold by startups created by academic researchers, in order to gauge the relation between different university and industry technology transfer policy models and innovation.

6. Policy Recommendations

As long as policy makers impose a single pathway for technology transfer by law, there is an increasing risk of making more and more difficult the formal (and informal) relationships between faculty and industry that have been historically at the core of technology transfer in Europe. The university ownership model is built upon a linear model of technology transfer that underestimates the importance of interactions between the inventor and licensee and, on the contrary, overestimates the brokerage role played by the TTO. Using the words of Kenney and Patton (2011) "[…] in too many cases in the university ownership model, the TTO, which owns the invention, is the least knowledgeable actor in a licensing relationship". This "informationally disadvantaged position" may retard technology diffusion and, in some circumstances, may induce inventors to use the grey market to transfer their inventions.

Altogether, these considerations call to consider alternative or complementary approaches to the model of 'university patent ownership and licensing via the university TTO'. Bradley et al. (2013) argue that "a linear model of technology transfer is no longer sufficient or perhaps even no longer relevant". One of the drawbacks of this approach has been to put too much emphasis on the importance of patents as the primary output in the technology transfer process, overlooking other mechanisms for commercialization (Bradley et al., 2013). These other mechanisms include joint laboratories between academia and industry, spin offs, research contracts, sponsored research, mobility of researchers, joint publications, conferences, expositions and specialized media, informal contacts with professional networks, the flow of graduates from university to industry or simply serendipity (Bercovitz and Feldman, 2008; Heinzl et al., 2008). Some of these channels are informal and do not need intermediation, others can face informational and cultural barriers as those mentioned by Bradley et al. (2013) for US universities, which are largely applicable to European universities too: "insufficient rewards for university researchers, university-industry culture clashes, bureaucratic inflexibility, unskilled and understaffed TTOs, lack of entrepreneurial talent throughout the university, the perception of declining federal support to R&D and the concern that university-industry cooperation will interfere with academic freedom, and arguably the existence of the traditional linear view of technology transfer itself." Bradley et al. (2013) recommend to reward technology transfer in promotion and tenure positions and to adapt university structures to be able to facilitate seamless technology transfer activities by having specialized, decentralized and autonomous TTOs with staff having marketing, technical and negotiation skills.

Going back to patents and to the issue of who should own faculty inventions or, in other words, who should be in charge of taking the decisions regarding their commercialization the debate continues in the US and in Europe. Foley (2012) recalls that the university ownership model proposed by the Bayh-Dole Act was in principle restricted to inventions from federally funded research and proposes a new approach to IP management and industrially funded research, such as the one at Penn University, a US top-tier research institution, which involves "letting the ownership of the IP developed with industrial funds flow back to the sponsor". In particular, the new approach intends to be based on a more flexible stance, where "the value to Penn State of industry sponsored research lies in research itself, in the support of that research and in the relationship with the partner, not in the creation and ownership of IP" and "the best agreement is the simplest form of agreement that is necessary and sufficient to meet the needs of the program and reduce negotiation to a minimum."

Without distinguishing by the source of funds, Litan et al. (2008) propose four alternative approaches, ranging from the more radical model of "faculty loyalty" to the more conservative model of 'regional alliances'. In the 'faculty loyalty' model, university professors retain the ownership of their inventions and universities anticipate that loyal faculty will give back to the institution some of the returns in case of successful commercialization. In this case, the university risks not obtaining sufficient returns from having let the professors use its infrastructure to carry out their inventions. In a second model, called 'free agency', university professors are free to choose a third party (or themselves) to commercialize their invention, instead of the university TTO provided they return a share of their profits to the university. The drawback in this case is that faculty may lack the resources to use agents different from the TTO. In a third model, web-based, the commercialization is done via online marketplaces and the role of the TTO is minimized. The challenge here is to have sufficient Internet traffic for the marketplace and acceptance from both buyers and sellers of this alternative way of establishing contact. The fourth and last model proposed by these authors is one based on regional alliances, where different universities come together to build critical mass in terms of TTO staff marketing and negotiation skills and the portfolio of the IP available.

Focusing on Europe, one of the conclusions of the EPO-OECD-TUM conference "Creating Markets from Research Results" held in Munich in May 2013[32] was that technology transfer offices at universities should become "enablers" of research collaborations with industry; become managers of multiple and complex relations, rather than simply managers of IP filings. In that respect, experts gathered for the conference considered that "bundling offerings across institutions, within countries and cross-border, will increase the attractiveness of university offerings for industry, reduce transaction costs and facilitate collaboration, especially in technological domains where patent portfolios and families are much more relevant than individual patents. But there is a limit to the concentration of TTOs: personal contact and proximity to researchers is important".

Alliances, combined with increasingly professionalized TTOs and complementary online match-making platforms, may be the way forward for Europe, provided steps are taken to avoid common mistakes. For instance, online market places would only work if they have continuous support, sufficient visibility and avoid duplication that only scatters attention, all features difficult to maintain when the initiative is publicly funded and priorities change with the political cycle. As regards alliances, it should be taken into account that they may not be beneficial for all, given the large degree of heterogeneity that characterizes the university system within and across countries. Imposing the alliances by law, rather than letting them emerge voluntarily, may lead to important coordination challenges and disputes when the leaders do not see benefit in it, and they are only attractive to the laggards. They would also have to be designed with care, to avoid imposing another administration layer to the process and have the opposite effect as intended.

As for ownership of the IP, we believe that the spotlight should not be put on 'who owns' but on 'who commercializes the invention and how it can be best done'. Who is ultimately the owner of the IP should not matter so much provided universities keep records of the inventions developed by their staff. Moreover, when looked through the glass of economic efficiency, the model of free agency is the one with highest chances to win. Taking this into account, we propose the following:

- *New official metrics based on university-invented patents.* University-invented patents should enter the metrics that are so relevant for their institutional funding and competition at the national and international level, and not just university-owned patents.[33] Moreover, university-invented patents could be used as signals to attract public and private funds for follow up research.

[32] https://www.iprhelpdesk.eu/node/2162

[33] Already adopted by Italy's research assessment exercise: http://www.anvur.it/attachments/article/880/Manuale%20di%20valutazione%20TM~.pdf

- *IP ownership at the institutional level by default (alone or jointly with sponsor).* No professor's privilege would be introduced as an exception to the general law on employee inventions, to increase legal security and because it may only bring uncertainty and opacity in the system, with no proven advantages for academic patenting. At the same time, universities would have to be flexible at the time of negotiations for industry sponsored research, favoring co-ownership when the university contribution merits it or the invention has benefited from a mix of public and private funds.
- *Delegation of IP management to the inventor and free agency for commercialisation.* The professor (inventor of the IP) would be the one to decide how to manage the IP. Thus, even though he would not be the registered owner, the institution would delegate the relevant decisions regarding IP management to him. An option that he could accept or refuse, depending on his resources and entrepreneurial character. If he accepted, the model of free agency would apply and then the university TTO could be one possible facility to commercialize university inventions, but not the only one. The university, in all cases, would receive a share of the returns, negotiable ex ante on a case by case basis, with some minimum threshold. In the case of research funded entirely since the beginning by the business sector, because of free agency, the parties could agree to leave the IP to the firm financing the research.

Setting up support infrastructures and allowing for university owned patents might provide incentives to lower patenting barriers for researchers who are unable to commercialize their inventions on their own or cover the costs to choose third parties to do so. Allowing the inventors to manage their IP (by delegation) may be optimal when they are good entrepreneurs and are better at finding a good match for the invention than the TTO. In such case they would also have the incentives to increase their effort in the commercialization and development phase and share their profits with the university administration. This double regime, by creating external competition among universities, and internal competition for TTOs within universities, might push the latter to renew and to be more efficient in order to induce academic inventors to disclose their inventions and increase their chances to reach the market.

References

Agrawal, A. (2006). Engaging the inventor: exploring licensing strategies for university inventions and the role of latent knowledge. *Strategic Management Journal*, *27*(1), 63-79.

Arqué-Castells, P., Cartaxo, R. M., García-Quevedo, J., and Godinho, M. M. (2016). Royalty sharing, effort and invention in universities: Evidence from Portugal and Spain. *Research Policy*, *45*(9), 1858-1872.

Arundel, A., Casali, L., and Hollanders, H. (2015). How European public sector agencies innovate: The use of bottom-up policy-dependent and knowledge-scanning innovation methods. *Research Policy*, *44*(7), 1271–1282.

Azagra-Caro, J. M. (2011). Do public research organisations own most patents invented by their staff?. *Science and Public Policy*, *38*(3), 237–250.

Azagra-Caro, J. M., Carayol, N., and Llerena, P. (2006). Patent production at a European research university: exploring evidence at the laboratory level. *Journal of Technology Transfer*, *31*(3), 257–268.

Balconi M., Breschi,S.and Lissoni F. (2004), "Networks of inventors and the role of academia: an exploration of Italian patent data" , *Research Policy*, 33(1), 127-14

Baldini, N., Grimaldi, R., and Sobrero, M. (2006). Institutional changes and the commercialization of academic knowledge: A study of Italian universities' patenting activities between 1965 and 2002. *Research policy*, *35*(4), 518-532.

Banal-Estañol, A. and Macho-Stadler, I. (2010).Scientific and Commercial Incentives in R&D: Research versus Development, *Journal of Economics & Management Strategy*, 19 (1), 185–221.

Becher, G., Gering, T., Lang, O. and Schmoch, U. (1996). Patentwesen an Hochschulen, Bonn: Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie

Bercovitz, J. and Feldman, M. (2008). Academic entrepreneurs: Organizational change at the individual level. *Organization Science*, *19*(1), 69-89.

Biglaiser, G. (1993). Middlemen as experts. *The RAND journal of Economics*, 212-223.

Blaug, S., Chien, C., and Shuster, M. J. (2004). Managing innovation: university-industry partnerships and the licensing of the Harvard mouse. *Nature biotechnology*, *22*(6), 761-763.

Bourelos, E., Magnusson, M. and McKelvey, M. (2012). Investigating the complexity facing academic entrepreneurs in science and engineering: the complementarities of research performance, networks and support structures in commercialisation, Cambridge Journal of Economics, 36(3), 1,751–780

Bradley, S. Hayter, C. and Link, A. (2013). Models and Methods of University Technology Transfer. *Foundations and Trends in Entrepreneurship*, *9*(6), 571-650.

Braunerhjelm, P. and Svensson, R. (2010). The Inventor's Role: Was Schumpeter Right? *Journal of Evolutionary Economics*, *20*(3), 314-44.

Bulut, H. and Moschini, G. (2006). Patents, trade secrets and the correlation among R&D projects. *Economics Letters*, *91*(1), 131-137.

Callaert, J., Du Plessis, M., Grouwels, J., Lecocq, C., Magerman, T., Peeters, B., Song, X., Van Looy, B., and Vereyen, C. (2011). Patent statistics at Eurostat: Methods for regionalisation, sector allocation and name harmonisation. *Eurostat Methodologies and Working Papers*, 72 pp. Luxembourg: European Union.

Callaert, J., Du Plessis, M., Van Looy, B. and Debackere, K. (2013). The impact of academic technology: do modes of involvement matter? The Flemish case, *Industry and Innovation*, 20(5), 456-472.

Carayol, N. and Sterzi, V. (2018). The Transfer and Value of Academic Inventions when the TTO is one option. Mimeo.

Cassi, L. and Wane, I. (2013). Inventivité et propriété intellectuelle des établissements d'enseignement supérieur: une méthodologie originale d'identification des brevets, Observatoire des Sciences et des Techniques. Point Methodologique, February 2013.

Chardonnens, F. (2010). Legislation And Technology Transfer In Switzerland. *Nouvelles-Journal of the Licensing Executives Society*, *45*(4), 261.

Chukumba, C. and Jensen, R. (2005). *University invention, entrepreneurship, and start-ups* (No. w11475). National Bureau of Economic Research.

Cohen, W. M., Nelson, R. R., and Walsh, J. (2002). Links and impacts: the influence of public research on industrial R&D. *Management Science*, *48*(1), 1–23.

Colaianni, A. and Cook-Deegan R. (2009). Columbia University's Axel Patents: Technology Transfer and Implications for the Bayh-Dole Act. *Milbank Quarterly*, *87*(3), 683-715.

Colyvas, J., Crow, M., Gelijns, A., Mazzoleni, R., Nelson, R.R., Rosenberg N., and Sampat, B.V. (2002) How Do University Inventions Get into Practice? *Management Science*, 48, 61-72.

Crespi, G. A., Geuna, A., and Nesta, L. (2007). The mobility of university inventors in Europe. *The Journal of Technology Transfer 32*(3), 195–215.

Crespi, G. A., Geuna, A., Nomaler, Ö., and Verspagen, B., (2010). University IPRs and knowledge transfer: is university ownership more efficient? *Economics of Innovation and New Technology*, *19*(7), 627-648.

Czarnitzki, D., Glänzel, W., and Hussinger, K., (2009). Heterogeneity of patenting activity and its implications for scientific research. *Research Policy*, *38*(1), 26-34.

Czarnitzki, D., Hussinger, K., and Schneider. C. (2012). The nexus between science and industry: evidence from faculty inventions. *The Journal of Technology Transfer*, 37 (5): 755-776.

Czarnitzki, D., Doherr, T., Hussinger, K., Schliessler, P., and Toole A. A. (2015). Individual versus Institutional Ownership of University-discovered Inventions. *ZEW Discussion paper*, no. 15-007.

Czarnitzki, D., Doherr, T., Hussinger, K., Schliessler, P., and Toole A. A. (2016). Knowledge created markets. The influence of entrepreneurial support and patent rights on academic entrepreneurship. *European Economic Review*, *86*, 131-146.

Czarnitzki, D., Glänzel, W., and Hussinger, K. (2007). Patent and publication activities of German professors: An empirical assessment of their co-activity. *Research Evaluation*, *16*(4), 311-319.

Damsgaard, E. F. and Thursby, M. C. (2013). University entrepreneurship and professor privilege. *Industrial and Corporate Change*, *22*(1), 183-218.

Debackere, K. and Veugelers R., (2005). The role of academic technology transfer organizations in improving industry science links. *Research Policy, 34*(3), 321-342.

Dechenaux, E., Thursby, M., and Thursby, J. (2009). Shirking, sharing risk and shelving: The role of university license contracts. *International Journal of Industrial Organization*, *27*(1), 80-91.

Della Malva, A., Lissoni, F., and Llerena, P. (2013). Institutional change and academic patenting: French universities and the Innovation Act of 1999. *Journal of Evolutionary Economics*, *23*(1), 211-239.

Dornbusch, F., Schmoch, U., Schulze, N. and Bethke N. (2013). Identification of university-based patents: A new large-scale approach. *Research Evaluation, 22*(1), 52-63.

Dosi, G., Llerena, P., and Labini, M. S. (2006). The relationships between science, technologies and their industrial exploitation: An illustration through the myths and realities of the so-called 'European Paradox'. *Research policy*, *35*(10), 1450-1464.

Eisenberg, R. S. (1996). Public research and private development: patents and technology transfer in government-sponsored research. *Virginia Law Review*, *82*, 1663-1727.

Ejermo, O. and J. Källström (2016), What is the causal effect of R&D on patenting activity in a "professor's privilege" country? Evidence from Sweden, Small Business Economics. 47, p. 677-694.

Ejermo, O. and Toivanen, H. (2018). University invention and the abolishment of the professor's privilege in Finland. *Research Policy*, *47*(4), 814-825.

Etzkowitz, H. (1998). The norms of entrepreneurial science: cognitive effects of the new university–industry linkages. *Research policy*, *27*(8), 823-833.

Etzkowitz, H. (2003a). Innovation in innovation: the triple helix of university-government-industry relations. *Social Science Information*, *42*(3), 293-337.

Etzkowitz, H. (2003b). Research groups as 'quasi-firms': the invention of the entrepreneurial university. *Research Policy*, *32*(1), 109-121.

Evans, J. (2010). Industry Induces Academic Science to Know Less about More. *American Journal of Sociology*, *116*(2), 389-452.

Feldman, M., Colaianni, A., and Liu, K. (2005). *Commercializing Cohen-Boyer 1980-1997*. Kauffman Foundation.

Fischer, T. and Leidinger, J. (2014). Testing patent value indicators on directly observed patent value—An empirical analysis of Ocean Tomo patent auctions. *Research Policy*, *43*(3), 519-529.

Foley, H. C. (2012). A new approach to intellectual property management and industrially funded research at Penn State. *Research-Technology Management*, *55*(5), 12-17.

Gallini, N., Wright, B. D. (1990). Technology transfer under asymmetric information. *The Rand Journal of Economics, 21*, 147-160.

Geuna, A. and Muscio, A. (2009). The Governance of University Knowledge Transfer: A Critical Review of the Literature. *Minerva*, *47*(1), 93–114.

Geuna, A. and Rossi, F. (2011). Changes to university IPR regulations in Europe and the impact on academic patenting. *Research Policy*, *40*(8), 1068-1076.

Godin, B. (2006). The Linear model of innovation the historical construction of an analytical framework. *Science, Technology & Human Values*, *31*(6), 639-667.

Greenbaum, D. and Scott, C. (2010). Hochschullehrerprivileg—A Modern Incarnation of the Professor's Privilege to Promote University to Industry Technology Transfer. *Science Technology and Society, 15*, 55-76.

Grimaldi, R., Kenney, M., Siegel D., and Wright, M. (2011). 30 years after Bayh–Dole: reassessing academic entrepreneurship. *Research Policy*, *40*(8), 1045–1057.

Harhoff, D., Narin, F., Scherer, F. M., and Vopel, K. (1999). Citation frequency and the value of patented inventions. *Review of Economics and Statistics*, *81*(3), 511-515.

Harhoff, D. and Reitzig, M. (2004). Determinants of opposition against EPO patent grants—the case of biotechnology and pharmaceuticals, *International Journal of Industrial Organization,* 22 (4), 443-480.

Heinzl, J., Kor, A., Orange, G., and Kaufmann, H. (2008). Technology transfer model for Austrian higher education institutions. Presented at the European and Mediterranean Conference on Information Systems, May 25-26, 2008.

Hellmann, T. (2007). The role of patents for bridging the science to market gap. *Journal of Economic Behavior and Organization, 63*(4), 624-647.

Henderson, R., Jaffe, A. B., and Trajtenberg, M. (1998). Universities as a source of commercial technology: a detailed analysis of university patenting, 1965–1988. *Review of Economics and statistics*, *80*(1), 119-127.

Hirschey, M. and Richardson, V. J. (2004). Are scientific indicators of patent quality useful to investors?. *Journal of Empirical Finance*, 11(1), 91-107.

Hughes, S. S. (2011). *Genentech: the beginnings of biotech*. University of Chicago Press.

Huyghe, A., Knockaert, M., Piva, E., and Wright, M. (2016). Are researchers deliberately bypassing the technology transfer office? An analysis of TTO awareness. *Small Business Economics*, *47*(3), 589-607.

Hvide, H.K. and Jones, B.F. (2018). University Innovation and the Professor's Privilege. *American Economic Review*, 108(7), 1860-98.

Iversen, E., Gulbrandsen, M., and Klitkou, A. (2007). A baseline for the impact of academic patenting legislation in Norway. *Scientometrics*, *70*, 393-414.

Jaffe, A.B., Trajtenberg, M. and M. Fogarty (2000). Knowledge spillovers and patent citations: Evidence from a survey of inventors. *American Economic Review Papers and Proceedings* 90(2): 215-218.

Jaffe, A., and De Rassenfosse, G. (2017). Patent citation data in social science research: overview and best practices, *Journal of the Association for Information Science and Technology*, 68(6): 1360–1374

Jensen, R. and Thursby, M. (2001). Proofs and prototypes for sale: the licensing of university inventions. *American Economic Review*, *91*(1), 240-259.

Jensen R. A., Thursby J. G., and Thursby M. C. (2003). Disclosure and licensing of university inventions: 'The best we can do with the s**t we get to work with'. *International Journal of Industrial Organization*, *21*, 1271-1300.

Joly, P. B. and Mangematin, V. (1996). Profile of public laboratories, industrial partnerships and organisation of R & D: the dynamics of industrial relationships in a large research organisation. *Research Policy*, *25*(6), 901-922.

Kenney, M. and Patton, D., (2009). Reconsidering the Bayh-Dole act and the current university invention ownership model. *Research Policy*, *38*(9), 1407-1422.

Kenney, M. and Patton, D. (2011). Does inventor ownership encourage university research-derived entrepreneurship? A six university comparison. *Research Policy*, *40*(8), 1100-1112.

Kline (1985). Research, Invention, Innovation and Production: Models and Reality, Report INN-1, March 1985, Mechanical Engineering Department, Stanford University.

Kline, S.J. and Rosenberg, D. (1986). An overview of innovation. In R. Landau & N. Rosenberg (eds.), The Positive Sum Strategy: Harnessing Technology for Economic Growth. Washington, D.C.: National Academy Press, 275–305.

Kumar, M. N. (2010). Ethical conflicts in commercialization of university research in the post-Bayh Dole era. *Ethics and Behavior*, *20*(5), 324–351.

Lanjouw, J. O. and Schankerman, M. (2004). Patent Quality and Research Productivity: Measuring Innovation with Multiple Indicators. *The Economic Journal*, *114*(495), 441-465.

Levin, R. C., Klevorick, A. K., Nelson, R. R., Winter, S. G., Gilbert, R., and Griliches, Z. (1987). Appropriating the returns from industrial research and development. *Brookings papers on economic activity*, *1987*(3), 783-831.

Lach, S. and Schankerman, M. (2008). Incentives and Invention in Universities. *RAND Journal of Economics*, *39*(2), 403-433.

Lawson, C. (2013). Academic Inventions Outside the University: Investigating Patent Ownership in the UK. *Industry and Innovation*, *20*(5), 385-398.

Lawson, C. and Sterzi, V. (2014). The role of early-career factors in the formation of serial academic inventors. *Science and Public Policy*, *41*(4), 464-479.

Levy, M. (2015). Why Universities Oppose Real Patent Reform: Money, Patent Progress http://www.patentprogress.org/2015/05/07/why-universities-oppose-real-patent-reform-money/

Lissoni, F. (2010). Academic inventors as brokers. *Research Policy*, *39*(7), 843-857.

Lissoni, F. (2013). Academic Patenting in Europe: A Reassessment of Evidence and Research Practices. *Industry and Innovation*, *20*(5), 379–384.

Lissoni, F., Llerena, P., Mckelvey, M., and Sanditov, B. (2008). Academic patenting in Europe: new evidence from the KEINS database. *Research Evaluation*, *17*(2), 87-102.

Lissoni, F., Lotz, P., Schovsbo, J., and Treccani, A. (2009). Academic patenting and the professor's privilege: Evidence on Denmark from the KEINS database. *Science and Public Policy*, *36*(8), 595-607.

Lissoni, F., Pezzoni, M., Potì, M. B., and Romagnosi, S. (2013). University autonomy, the professor privilege and academic patenting: Italy, 1996-2007. *Industry and Innovation*, *20*(5), 399-421.

Lissoni, F. and Montobbio, F. (2015). The ownership of academic patents and their impact. *Revue économique*, *66*(1), 143-171.

Litan, R. E., Mitchell, L., and Reedy, E. J. (2008). Commercializing university innovations: alternative approaches. *Innovation Policy and the Economy*, *8*, 31-57.

Lizzeri, A. (1999). Information revelation and certication intermediaries. *Rand Journal of Economics, 30*, 214-231.

Ljungberg, D., Bourelos, E. and McKelvey, M. (2013) Academic Inventors, Technological Profiles and Patent Value: An Analysis of Academic Patents Owned by Swedish-Based Firms, *Industry and Innovation*, 20(5), 473-487.

Loise, V. and Stevens, A. J. (2010). The Bayh-Dole Act turns 30. *Les Nouvelles*, *Licensing Executives Society International Journal*, December 2010, 185-194.

Macho-Stadler, I. and Perez-Castrillo D. (1991). Contrats de licences et asymétries d'information, *Annals of Economics and Statistics/Annales d'Economie et de Statistiques, 24*, 189-208.

Macho-Stadler, I., Martinez-Giralt, X., and Perez-Castrillo, J. D. (1996). The role of information in licensing contract design. *Research Policy*, *25*(1), 43-57.

Macho-Stadler, I., Pérez-Castrillo, D., and Veugelers, R. (2007). Licensing of university inventions: The role of a technology transfer office. *International Journal of Industrial Organization*, *25*, 483–510.

Maraut, S. and Martínez, C. (2014). Identifying author–inventors from Spain: methods and a first insight into results. *Scientometrics*, *101*(1), 445-476.

Martin, M.J. (2007). University perspective on commercialization of IP. *Research-Technology Management*, 50(5), pp.13-16.

Martínez, C., Azagra-Caro, J. M., and Maraut, S. (2013). Academic inventors, scientific impact and the institutionalisation of Pasteur's Quadrant in Spain. *Industry and Innovation*, *20*(5), 438–455.

Markman, G. D., Gianiodis, P. T., and Phan, P. H. (2008). Full-time faculty or part-time entrepreneurs. *IEEE Transactions on Engineering Management*, *55*(1), 29-38.

Martinez, C. and Guellec, D. (2004). Overview of recent changes and comparison of patent regimes in the United States, Japan and Europe. *Chapter in Patents, Innovation and Economic Performance, OECD, Paris*, 127-162.

Mejer, M. (2011). Entrepreneurial Scientists and their Publication Performance. An Insight from Belgium. *ECARES Working Paper 2011–017*. European Center for Advanced Research in Economics and Statistics. Université Libre de Bruxelles. Brussels.

Merrill, S. A. and Mazza, A. M. (2011). *Managing university intellectual property in the public interest.* National Academies Press.

Meyer, M., Siniläinen, T., and Utecht, J. T. (2003). Towards hybrid Triple Helix indicators: A study of university-related patents and a survey of academic inventors. *Scientometrics*, *58*, 321-350.

Meyer, M., Du Plessis, M., Tukeva, T., and Utecht, J. T. (2005). Inventive output of academic research: A comparison of two science systems. *Scientometrics*, *63*(1), 145-161.

Mowery, D. C., and Ziedonis, A. A. (2000). Numbers, quality, and entry: How has the Bayh-Dole Act affected US university patenting and licensing? *Innovation Policy and the Economy*, *1*, 187-220.

Mowery, D.C., R.R. Nelson, B.N. Sampat, and A.A. Ziedonis, 2004, Ivory Tower and Industrial Innovation: University Industry Technology Transfer Before and After Bayh-Dole, Stanford University Press.

Mowery, D. and Sampat, B. (2005). The Bayh-Dole Act of 1980 and University-Industry Technology Transfer: A Model for Other OECD Governments? *Journal of Technology Transfer*, *30*, 115–127.

OECD (2010). *Main Science and Technology Indicators 2010*. OECD Publishing: Paris.

Orsenigo, L. and Sterzi, V. (2010). Comparative Study of the use of patents in different industries. *KITes working paper 33/2010*. Bocconi University.

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., Fini, R., Geuna, A., Grimaldi, R., Hughes, A., Krabel, S., Kitson, M., Llerena, P., Lissoni, F., Salter, A., Sobrero, M. (2013). Academic engagement and commercialisation: A review of the literature on university–industry relation. *Research Policy*, *42*(2), 423–442.

Poyago-Theotoky, J., Beath, J., and Siegel, D. S. (2002). Universities and fundamental research: reflections on the growth of university–industry partnerships. *Oxford Review of Economic Policy*, *18*(1), 10-21.

Pezzoni,M., Lissoni, F. and Tarasconi, G. (2014). How to kill inventors: testing the Massacrator© algorithm for inventor disambiguation, *Scientometrics*, Springer, 101(1), 477-504.

Raffo, J., and Lhuillery, S. (2009). How to play the "Names Game": Patent retrieval comparing different heuristics. *Research Policy*, 38(10), 1617-1627.

Roberts, E. B. and Peters, D. H. (1981). Commercial innovation from university faculty. *Research Policy, 10*(2), 108-126.

Rosell, C. and Agrawal. A. (2009). Have university knowledge flows narrowed? Evidence from patent data. *Research Policy, 38*, 1–13.

Saragossi, S. and van Pottelsberghe de la Potterie, B. (2003). What patent data reveal about universities: the case of Belgium. *The Journal of Technology Transfer*, *28*(1), 47-51.

Schacht, W. (2012). The Bayh-Dole Act: Selected Issues in Patent Policy and the Commercialization of Technology. *CRS Report for Congress,* https://fas.org/sgp/crs/misc/RL32076.pdf

Schmiemann, M. and Durvy, J. N. (2003). New Approaches to Technology Transfer from Publicly-Funded Research. *The Journal of Technology Transfer*, *28*(1), 9-15.

Schmoch, U. (2007). Patentanmeldungen aus deutschen Hochschulen. *Studien zum deutschen Innovationssystem no. 10-2007.*

Schmoch, U. (2008). Concept of a technology classification for country comparisons. *Final report to the World Intellectual Property Office (WIPO).* Karlsruhe: Fraunhofer ISI.

Schoen, A., Heinisch, D., and Buenstorf, G. (2014). Playing the 'Name Game'to identify academic patents in Germany. *Scientometrics*, *101*(1), 527-545.

Schoen, A. and Buenstorf, G. (2013). When Do Universities Own Their Patents? An explorative Study of Patent Characteristics and Organizational Determinants in Germany. *Industry and Innovation*, *20*(5), 422-437.

Siegel, D. S., Waldman, D., and Link, A. (2003). Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: An exploratory study. *Research Policy*, *32*, 27–48.

Siegel, D., Waldman, D., Atwater, L., and Link, A. (2004). Toward a model of the effective transfer of scientific knowledge from academicians to practitioners: qualitative evidence from the commercialization of university technologies. *Journal of Engineering and Technology Management*, *21*, 115–142.

Spilling, O. R., Brorstad, S. B., Iversen, E. J., Rasmussen, E., and Solberg, E. (2015). Virkemiddelapparatet for kommersialisering av forskning – status og utfordringer (kap 2: Patentering) Rapport 18/2015.

Squicciarini, M., Dernis, H., and Criscuolo, C. (2013). Measuring patent quality. *OECD DSTI Working Paper 2013/3.*

Sterzi, V. (2013). Patent quality and ownership: An analysis of UK faculty patenting. *Research Policy, 42*(2), 564-576.

Sterzi, V., Lissoni, F., and Pezzoni, M. (2018). Patent Management by Universities: Evidence from Italian Academic Inventions. *Mimeo.*

Stummer C., Günther M., and Backs, S. (2013). A survey on academic patents at Austrian universities: Methodology and initial results. *WP 2013-01*, Chair of Innovation and Technology Management, Bielefeld University.

Takenaka, T. (2005). Technology licensing and university research in Japan. *International Journal of Intellectual Property-Law, Economy and Management*, *1*(1), 27-36.

Thursby, J., Jensen, R.., and Thursby, M. (2001). Objectives, Characteristics and Outcomes of University Licensing: A Survey of Major U.S. Universities. *Journal of Technology Transfer*, *26*, 59-72.

Thursby, J. G. and Thursby, M. C. (2002). Who is selling the ivory tower? Sources of growth in university licensing. *Management Science*, *48*(1), 90-104.

Thursby, J. G. and Thursby, M. C. (2003). University Licensing and the Bayh-Dole Act. *Science*, *301*.

Thursby, J., Fuller, A., and Thursby, M. C. (2009). US faculty patenting: inside and outside the university. *Research Policy*, *38*(1), 14-25.

Townes, C. H. (1999). *How the laser happened: Adventures of a scientist.* Oxford University Press.

Valentin, F. and Jensen, R. L. (2007). Effects on academia-industry collaboration of extending university property rights. *The Journal of Technology Transfer*, *32*(3), 251-276.

Von Hippel, E. (2007). *The sources of innovation.* Springer.

Von Proff, S., Buenstorf, G., and Hummel, M. (2012). University Patenting in Germany before and after 2002: What Role Did the Professors' Privilege Play? *Industry and Innovation*, *19*, 23-44.

Wallmark, J. T. (1997). Inventions and patents at universities: the case of Chalmers University of Technology. *Technovation*, *17*(3), 127-139.

Wright, B. D., Drivas, K., Lei, Z., and Merrill, S. A. (2014). Industry-funded academic inventions boost innovation. *Nature*, *507*(7492), 297-299.

Yeh, R. M. (2012). The Public Paid for the Invention: Who Owns It? *Berkeley Technology Law Journal*, *27*, 453-500.

Zuniga, P. (2011). The state of patenting at research institutions in developing countries: policy approaches and practices. Background Report to the publication: Intellectual property and the new innovation paradigms. Washington DC.

ANNEX

Table A1: Available evidence on the impact of IP regime changes in Europe

Country	Change	Study	Method	Result
Norway	2003 abolishment of university professor's privilege (exception to employer ownership of IP)	Iversen, Gulbrandsen, Klitkou (2007)	Descriptive, trends of patent filings by different types of inventors (matching employee names to inventor names)	828 Norwegian patents filed 1998-2003 with public sector researchers as inventors. Not enough to assess post-reform changes, but policy change had already been announced in 2002. Observe a reduction in patent filings invented by public sector researchers (universities and PROs), from 12% in 1998-2002 to 10% in 2003.
		Spilling, Brorstad, Iversen, Rasmussen and Solberg (2015)	Descriptive, trends of patent filings by different types of inventors (matching employee names to inventor names)	2244 Norwegian patents filed 1999-2013 with public sector researchers as inventors. The share of researchers' patents falls slightly from 13.4% in 1999-2003 to 11.7% in 2004-2008. The authors warn that the climate for patenting changed greatly during the period (e.g. dotcom bubble prior to the policy change, financial crisis after, EPC accession in 2008). They also observe a 1% increase in university-owned patent filings suggesting a shift in ownership.
		Hvide and Jones (2018)	Difference-in-Difference regression, comparing patents and start-ups of university inventors and all other inventors (matching employee names to inventor names). Regressions include controls (year, technology, demographics).	750 Norwegian patents filed in 1995-2010 with university inventors and 128 start-ups created by university employees with a PhD between 2000 and 2007. Difference in difference regressions show an approximate 50% decline in the rate of new venture creation and patenting by university researchers after the reform. The quality of university start-ups and patents also appears to have declined.
Denmark	2000 abolishment of university professor's privilege (exception to employer ownership of IP)	Valentin and Jensen (2007)	Difference-in-Difference regression, comparing of university-industry collaboration in Denmark (treated) and Sweden (control) before and after the change in Denmark	3640 inventor contributions behind the 1,087 patents filed by Danish and Swedish dedicated biotech firms in 1990–2004, Difference-in-Difference show significant reductions in contributions from Danish domestic academic inventors, and an increase of non-Danish academic inventors. They also observe a moderate increase in academic inventions channeled into university owned-patents after the change.
		Lissoni et al (2009)	Descriptive. Academic patenting obtained by matching names of Danish academic personnel to inventors in EPO applications	Almost 70% of all Danish academic patents filed at EPO and identified in the study by matching inventors to academics active in 2001 and 2005 are owned by business companies. Although the extent of academic patenting before the policy change in 2000 is underestimated (i.e. no information on professors who retired before 2001), the study finds evidence of a 'property shift' with universities replacing many individual scientists as applicants for patents over the latter's inventions. But the bulk of academic patents remain in the hands of business companies.
Germany	2002 abolishment of university professor's privilege (exception to employer ownership of IP)	Schmoch (2007)	Descriptive. Academic patenting data obtained by identifying inventors with Prof. titles.	No evidence that the overall numbers of university-invented patents in Germany increased after 2002 (as cited in von Proff et al 2012)
		Von Proff et al (2012)	Multinomial logit on types of ownership of academic inventions. Patenting data identified with Prof. titles as well as, as robustness test, invented by staff of six selected German universities.	1991-2006 German patent filings invented by university professors (sample 5624). Unchanged number of university-based inventions. Patents filed after 2002 are much more likely to be university-owned, as the likelihood of all other forms of ownership decreases.
		Dornbusch et al (2013)	Descriptive. Academic patenting data obtained by matching names of Scopus scientific authors affiliated to German universities to names of inventors. [34]	1996-2007 EPO and German patent filings with German university inventors. Slight increase in EPO patent filings invented by German university professors between 2001 and 2007, but decrease in filings to the German Patent Office.
		Czarnitzki et al (2015)	Difference-in-Difference, comparing patents invented by German university and PRO researchers.	1995-2008 EPO and German patent filings (collapsed at family level) with German university and PRO researchers as inventors, excluding those with double affiliation. Patenting by professors with previous industry connections decreased after the change, patenting by professors without connections increased. Overall, university-invented patents decreased.

[34] Sensitive to coverage changes in Scopus over time and possible matching errors (type I and II) in very large sample (e.g. for 2006 only, they had to match 43,000 inventor names to 160,000 author names affiliated to a German university).

Table A1: Available evidence on the impact of IP regime changes in Europe

Country	Change	Study	Method	Result
		Czarnitzki et al (2016)	Difference-in-Difference, comparing patents and startups by German university and PRO researchers.	Patents and startups created by the German university and PRO researchers in Czarnitzki et al (2015) database (smaller sample because common names excluded for link with startups). No evidence of an increase in start-up companies by university researchers after the change above PRO researcher start-ups. Both groups declined.
Finland	2007 abolishment of university professor's privilege (exception to employer ownership of IP)	Ejermo and Toivanen (2018)	Difference-in-Difference, comparing patents invented by Finnish university and firm or PRO researchers.	1995-2010 EPO patents invented in Finland linked to Statistics Finland employee-employer register data. Patenting by individuals dropped by at least 29 percent after 2007. The decrease is even higher (46 percent) if 2004 is considered as the year of the policy change, given that the reform was announced then.
France	1999 Innovation Act and gradual creation of university TTOs before	Della Malva et al (2013)	Multinomial logit on choice of ownership for university invented patents, controlling for year of creation of the TTO. Year dummies to capture impact of 1999 Innovation Act (Loi Allegre).	1994-2002 EPO patents filed by French university professors from the KEINS database. The Innovation Act has increased the propensity of universities to retain property rights over their scientists' inventions, but having a TTO has a bigger influence and the creation of many TTOs predates the Act.
Italy	1989 University Autonomy and 2001 introduction of professors' privilege (restricted in 2005)	Lissoni et al (2013)	Probit regressions to estimate the conditional probability to observe an academic patent.	1996-2006 EPO filings invented by Italian university professors. The absolute number of academic patents has increased, their weight on total patenting by domestic inventors has decreased, and the share of academic patents owned by universities has more than tripled. The authors conclude that the increased autonomy of Italian universities, which has allowed them to introduce explicit IP regulations concerning their staff's inventions has effectively neutralized the introduction of the professor privilege.