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The Dynamics of French Universities in Patent Collaboration Networks

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Abstract

Innovation is a dynamic process whose complexity lies in networks among heterogeneous actors, with collaboration often ending in *patent co-ownership*. Governments introduced many policies to redefine the role of universities in research collaboration once acknowledging their value in scientific knowledge. This paper explores how *patent co-ownership* evolved in France after decisive policy interventions (1999, 2006, 2007). Using French co-patent data (1978-2018), we first employ Network Analysis to capture the evolution of centrality of French Universities. We then apply a Dif-in-Dif, incorporating a Propensity Score Matching (PSM), to investigate the potential causal relationship between policy interventions and the evolution of universities' centrality, contrasting with with French Public Research Organizations as well as German and Italian universities. Our results point to the increasing centrality gained by French universities in *patenting co-ownership* over the years and its essential role, as an innovator actor, in the French innovation system. Although the Innovation Act (1999) positively impacted their centrality, the impact of 2006-on legislation is either null or even negative, offsetting the initial trend.

Keywords: Innovation dynamics, Universities, Collaborative Patents, Network centrality, treatment effect.

JEL Codes: C54, D85, O32, O33, O34, O38

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1 Introduction

Innovation has been recognized as an evolutionary learning process based on dynamic and collaborative networks among heterogeneous actors. The interactions with the external environment and the system characteristics (geographical, sectoral, and institutional) encourage a constant transformation process, besides knowledge accumulation and transmission (Dosi, 1988; Cohen and Levinthal, 1989; Malerba, 1992; Dosi and Nelson, 2010).

Innovation literature struggled in capturing the intricate relationship existing between science, technology, and industry. Yet, one of the most far-reaching ideas assumes that these three elements co-evolve along coherent and long-term trajectories closely interacting in complex ways in multi-skills networks (Etzkowitz and Leydesdorff, 1995; Powell et al., 1996; Mina, 2009). The sectoral differences drive the exchanges and collaboration with the *external environment* to exploit the surrounding *scientific knowledge*, often ending in a co-evolutionary process of knowledge and industry organisation while patenting the discovery made (Malerba, 2004; Nesta et al., 2004a; Dosi et al., 2006; Breschi and Catalini, 2010).

Besides the technological dimension, innovation has both social and institutional ones. Several factors influence the risky invention-innovation process and science-based inventiveness: the information production, the inventor's talent, the investments in R&D, and the external sources of knowledge (Nelson, 1959; Arrow, 1962; Cohen and Levinthal, 1989, 1990; Bikard, 2018; Etzkowitz, 2003; Arora et al., 2015; Bianchini and Llerena, 2016; Bianchini et al., 2018, 2019; Crescenzi, 2021). More in detail, existing innovation literature has acknowledged the value of universities in knowledge production and basic and applied research. Governments have thus increasingly called for their proactive role in science, and technological development, driving them towards a new mission.

In line with existing empirical evidence, we develop our paper on the assumption that intrinsic to innovation and technological change are the frequent interactions in the industrial, innovative, and institutional settings (Freeman, 1995; Leoncini et al., 1996; Mina, 2009). Although institutional factors influence the establishment and direction of technological paradigms and the interplay between endogenous mechanisms and technological innovations, as pointed out in Dosi (1983), this dimension has not been fully covered in the literature. We believe that implementing new policies stimulate changes and create new incentives in the knowledge-transfer process, triggering a complex chain reaction in *patenting ownership* and interactions among institutions. To the best of our knowledge, only a few empirical studies assessed the impact of French policies in the innovation process, mainly focusing on *academic patenting* and *academic engagement* (Martínez and Sterzi, 2021; Carayol et al., 2019; Carayol and Carpentier, 2021). We thus believe that the existing investigations have underestimated the evolution of the interactions between companies and universities and grasped only a partial understanding of the dynamics in Intellectual Property Rights (IPRs). Recent arguments, summarised in Crescenzi et al. (2016), notice an increase in the number of collaborative inventions in recent decades, with a peak for co-patents in some technological fields.

This paper seeks to provide a complementary overview on French *co-patenting ownership*, used as an indicator of collaborative interactions. The aim is to validate its evolution over the last forty years by adopting three reforms: *Innovation Act* (1999), *Loi de programme pour la recherche* (2006), and *Loi relative aux libertés et responsabilités des universités* (2007). Although Arora et al. (2018) provide evidence on the role of governments strategies in knowledge transfer and university-industry interactions, the way organizational and institutional settings influence the importance of actors in co-patenting activities still needs to be addressed.

This paper presents an empirical investigation using *co-application patent data* in selected technological sectors, over 1978-2018, and extracted from PATSTAT latest versions (Autumn 2020 and Spring 2021). We first employ Network Analysis to capture the evolution of French universities' importance in co-patenting by quantifying their *centrality* in co-patenting network collaborations, besides the numbers and diversity of connections, after policy interventions[1]. We then run a Difference-in-Differences and complement our initial estimation strategy by incorporating a Kernel Propensity Score Matching (PSM). We explore the causal relationship between the adoption of these reforms and the evolution of their centrality in France, used as our *treatment group*. The treatment effect is contrasted with two control unaffected *control groups*: German and Italian universities French PROs. We find that French universities gained more centrality in *patenting co-ownership* over the years and became an essential actor in the French innovation system. Although the Innovation Act (1999) accelerated this process by boosting research commercialization and university patenting, positively impacting their centrality, the 2006-on reforms are either negative or null, offsetting the initial trend.

The remainder of this paper is structured as follows. Section 2 provides an overview of the existing body of literature. Section 3 presents the data. Section 4 describes the methodology. Section 5 discusses the main findings. Section 6 concludes.

[1] A more detailed discussion on what centrality captures is to be found in the methodology section 4.1.1

2 Literature Review

2.1 Interorganisational knowledge transfer

Knowledge creation is a vital component in the dynamic and collective innovation process. A vast body of literature strives to explain the conditions and factors influencing technology direction and knowledge transfer. First, the environment in which innovative actors move affect the capabilities, quality and efficiency of research and information exchange. Secondly, heterogeneous actors collaborate to combine new technological products and creative learning processes (Freeman, 1995; Dibiaggio and Nesta, 2005; Malerba and Lee, 2020). Knowledge coordination influence the division of labour, the structure and composition of final products, and the orientation of new research opportunities (Feldman et al., 2019; Mina, 2009). Last, the use of *scientific knowledge* and the integration of coherent and related competencies contribute to the diversification of the *knowledge base*, which is considered the essential factor of innovation, research, and innovative performance (Nesta and Saviotti, 2005).

Knowledge integration is not a random process but a rather complex one, based on economically valuable decisions and complementary to knowledge production. The cumulative and selective nature of knowledge affects *absorptive capacity* and explains the persistent differences among innovative actors. The ability to integrate knowledge increases the chances of gaining relevant information, besides shaping the evolution of science and technology (Arrow, 1962; Nelson, 1959, 1991). One such example is the propensity of firms to collaborate externally with a university, as explored by a vast body of literature. Labour division, combined with knowledge spillovers, increases the chances of granting a patent (Arora and Gambardella, 1994; Etzkowitz, 2003; Arora et al., 2018).

Radical innovation requires large amounts of knowledge, which differentiates under technical changes, technological regimes and phases: *generic and specific knowledge*, and *codified knowledge*. More in detail, the latter is a source of information to improve innovative performance and the distributional power of innovation system (Breschi et al., 2000; Brusoni et al., 2005; Bianchini et al., 2018). Knowledge may, however, remain not fully codifiable and transferable, lacking firms and organisations the *absorptive capacity* to master external knowledge (Cohen and Levinthal, 1989, 1990; Nelson, 1991; David and Foray, 1995; Bikard, 2018; Malerba and Lee, 2020; Arora et al., 2021; Bianchini et al., 2019).

Recent developments stress how knowledge accumulation evolves upon product development stages, sectoral diversity and distance, and knowledge perception (Eslami et al., 2018; Stephan et al., 2019). Although ample literature acknowledges the role of integrating scientific knowledge for improving innovative performance, technology portfolio and knowledge stocks alone are insufficient to fully explain the competitive advantage in the innovation system (Lindelöf and Löfsten, 2004; Bikard, 2018; Quatraro and Scandura, 2020).

Innovation stems from a complex interplay among knowledge codification, the labour market for scientists and technologists, innovators' appropriation strategies, geographical proximity, and well-regulated knowledge flows between academic institutions and firms. A large body of literature identified in the organizational arrangements (institutions, university system, government, and public policy) the driving factors of knowledge creation and innovation diffusion. Debates on how to increase university invention and technology transfer have pushed towards university ownership and institutional ownership models, despite some critics over its efficiency (Cohen and Levinthal, 1990; Patel and Pavitt, 1997; Dosi and Nelson, 2010; Malerba et al., 2013; Stephan et al., 2019; Feldman et al., 2019; Malerba and McKelvey, 2020). Recent contributions reveal that institutional setting shapes entrepreneurs' cognition and actions and affect their interaction with universities and PROs (Malerba and Pisano, 2019; Malerba and Lee, 2020; Malerba and McKelvey, 2020). Previous findings support the idea that geographical proximity, location, geographical or *spatial clustering* increase economic value and innovative output in patent applications and citations, despite their limits. An example is given by science-intensive firms (e.g., biotechnology, pharmaceuticals, and chemicals), which tend to locate near universities to benefit from knowledge spillovers (Breschi and Lissoni, 2004; Gittelman, 2007; Aharonson et al., 2014; Arora et al., 2018, 2021; Belenzon and Schankerman, 2013; Jaffe et al., 1993). Researchers mobility encourage knowledge spillovers and flow between firms and academia (Breschi and Lissoni, 2001). Nonetheless, national borders are perceived as the main hinders of knowledge diffusion (Singh and Marx, 2013).

2.2 The French case: Commercialising and patenting research

The increased use of Intellectual Property Rights (IPRs) in scientific research has sparked a vigorous academic and policy debate among economists over their impact on the innovation diffusion process (industrial dynamics, innovation rate and knowledge domains). Many previous studies acknowledged patent data as a valuable measure of knowledge transfer among innovative actors (e.g., firms, universities and PROs) and an indicator of innovation performance and geographic concentration (Dibiaggio and Nesta, 2005). Nonetheless, a stream of literature on patent regimes has questioned whether they are the most appropriate measures of innovation. Strong patent protection yields lower rates of innovation and product quality and hinders the innovation diffusion process (Malerba and Lee, 2020; Marengo et al., 2012). Additionally, Fontana et al. (2013) point out that *patent propensity* varies across industrial sectors, geographical areas, types of organizations and innovation.

Institutional arrangements and patent laws seem to influence the direction of technological innovation, patenting or secrecy rate, university-industry knowledge, and science transformation (Walsh and Huang, 2014; Raghupathi and Raghupathi, 2019). The adoption of institutional policies has encouraged a *patent explosion*, thus expanding the *patentability domain*. As extensively argued in Baldini et al. (2010), exogenous shocks, like governmental regulations, change the environment, and may induce *mimetic isomorphism*, namely the tendency of an organization to imitate another organization's structure as a response to uncertainty.

Inspired partly by the introduction of the Bayh-Dole Act in the USA during the 1980s, many European countries have enacted structural changes and targeted reforms from the 1990s-on, altering the rights of university-based innovations and pushing for a more active role of universities in technology and research transfer (Hvide and Jones, 2018; Baldini et al., 2006). The underlying reasons were the decisive role of universities in commercializing innovation and the poor performance of the European ones, compared to the North American ones. Both European and Asian countries felt legitimate in encouraging *patenting institutionalization* and university-firms collaboration awakening universities' interest in gaining profits from academic research. They started filing patent applications over publicly-funded research driving new dynamics in property rights ownership and the free flow of basic science (Crespi et al., 2007; Tartari and Breschi, 2012; Della Malva et al., 2013; Walsh and Huang, 2014; Chang, 2017). France has witnessed from the 1990s-on radical reforms in its public research and university IPR system to increase its socio-economic relevance. Although the attention to this sphere was remarkable already in the 1970s, the government made technology and knowledge transfer its political priority by addressing weaknesses in research and strengthening the collaborative exchanges between the public and the private sector (Geuna and Nesta, 2006; Smith, 2006; Bianchini and Llerena, 2016). In this regard, the government gradually introduced institutions and agencies, like Agence Nationale de Recherche (ANR), Institut national de la santé et de la recherche médicale (INSERM), and the Institut Carnot (Della Malva et al., 2013; Carayol et al., 2019; Carayol and Carpentier, 2021). However, the most significant reform occurred in 1999 with the adoption of the *Innovation Act* (or *Loi Allègre*). This act encouraged the research commercial exploitation, universities patents and licenses, the creation of Technology Transfer Offices (TTOs) for universities and PROs, the mobility from academia to a temporary position in companies, and the chance to perform consulting activities in firms (Carayol et al., 2019). As investigated in Lissoni and Montobbio (2015), French universities preferred to leave property rights to PROs before the Innovation Act, with a new trend after its adoption (with universities claiming ownership over their invention).

Two other significant changes occurred. First, the *Loi de Programme pour la Recherche* (2006) promoted the massive entry of firms into university missions to encourage scientific collaboration and strong support for private research to the extent that public research establishments can entrust the exploitation of research results to a private company. Then, the *Loi relative aux Libertés et Responsabilités des Université* (Loi LRU) (2007) enhanced the autonomy of French universities and decreased the dependence on PROs. Until then, French universities had never been the centre of French scientific research, which had been mainly conducted within the national laboratories or coordinated by the CNRS (National Center for Scientific Research) (Bruno and Orsenigo, 2003). As observed in Aghion et al. (2010), the greater the university autonomy, the higher the efficiency, performance productivity in local competition, and innovative output (patents and publications). This law recalled the importance of conducting scientific and technological research and disseminating the results discovered by universities by encouraging their filing of patents and licenses. The core idea is that higher education institutions should help spread innovation and research results being basic and applied complementary to one another.

Previous existing studies have investigated the increase of *academic engagement* and *academic patenting*. Besides corresponding to 5% of the European total patenting activity, they are one channel for transferring scientific and technological knowledge to industrial application, although they seem less valuable than company-owned ones, (Balconi et al., 2004; Tartari and Breschi, 2012; Chai and Shih, 2016; Perkmann et al., 2013; Lissoni, 2012). Another stream of literature focused on the increased importance of *academic inventors* in regional technological specialisations and local innovation (Singh, 2005; Breschi et al., 2008; Perkmann et al., 2013; Walsh and Huang, 2014; Perkmann et al., 2015; Chai and Shih, 2016; Kongsted et al., 2017; Sterzi et al., 2019; Bikard and Marx, 2020; Quatraro and Scandura, 2020).

Despite decades of research, the role of institutional structures in shaping organizational arrangements for university-industry collaboration remains under-researched. Few studies explore how legislative acts and institutional and organizational changes encourage new dynamics in *patenting co-application* among different institutions (firms, non-profit and universities) and influence patenting activities. The propensity to patent varies with legal and economic changes, thus affecting the benefits of patenting and the importance of the nature and strength of faculty-industry relationships (Czarnitzki et al., 2015; Perkmann and Walsh, 2007).

We intend to demonstrate that institutional setting and policy initiatives determine new technological trajectories and relationships among institutions, favouring some actors more than others in co-application patenting in science-based sectors.

2.3 Collaborative networks and the locus of innovation

Innovation has become a cooperative activity. Networks and external collaboration play a pivotal role in disseminating information, granting access to resources, and developing capabilities, competencies, and knowledge. Nowadays, firms are not the only leading innovator actor (Arora and Gambardella, 1994; Cohen and Levinthal, 1989; Dosi, 1983; Breschi and Lissoni, 2004; Cassi et al., 2008; Marzucchi et al., 2015; Crescenzi et al., 2016; Crescenzi, 2021).

Literature provides evidence that inter-organizational collaborative networks vary on economic sectors and regional activities and rely on different reasons: willingness to search, screen, and signal the external environment to gain knowledge and codify *tacit knowledge*; the need of achieving higher performance, and the incentives induced by innovation policies (Fontana et al., 2006; Nesta and Saviotti, 2005; Brusoni et al., 2005; Geuna and Nesta, 2006; Breschi and Catalini, 2010; Balconi et al., 2004; Crescenzi et al., 2016; Marzucchi et al., 2015; Bianchini et al., 2019). Recently, Crescenzi (2021) showed that public policies encourage R&D investments and facilitate collaboration between innovative actors. Its success depends, however, on the ability to exploit valuable scientific knowledge and shape the *knowledge base* (Powell et al., 1996; Nesta et al., 2004a; Malerba, 2004).

The increasing academic-industry research collaboration roots in the growing *outsourcing* strategies of firms since the 1980s. Such partnerships with non-profit actors that are not potential competitors reduce the hold-up problem and knowledge leakages threats for the firm than would a partnership with another private company generates, as pointed out in the Property-Rights Approach (Grossman and Hart, 1986; Grossman and Helpman, 2002).

Existing literature argues that the more open firms to external channels of knowledge, the higher the probabilities of gaining relevant information (Laursen and Salter, 2006; Leiponen and Helfat, 2010). External cooperation offers an opportunity to foster firms' specialization through strategic resources, reciprocal and bidirectional information exchanges, and knowledge transfer (Bikard, 2018; Lindelöf and Löfsten, 2004; Donegan and Feldman, 2019).

Despite some controversy, university-firm networks operate as catalysts for economic development and innovation. The private sector now perceives public science and university research as a source of complementary knowledge to the innovation performance rather than a perfect substitute for firm research (Arora et al., 2021). Acting as gatekeepers of knowledge, universities and intermediary organizations connect scientific and technological research communities with firms (Breschi and Catalini, 2010; Chai and Shih, 2016; Della Malva et al., 2013; Mina et al., 2009). Extensive literature has developed on the idea that heterogeneous partnerships or wide-range collaborative networks, involving a university or an excellent partner like a research centre, boost invention quality and output and commercialization of radical innovation (Perkmann et al., 2013, 2015; Walsh et al., 2016; Jonkers and Sachwald, 2018; Nishimura and Okamuro, 2011; Balconi et al., 2004; Gómez et al., 2020). In this regard, Crescenzi (2021) provide evidence that collaboration and complex networks of researchers, involving firms, universities and public agencies, is becoming the norm in driving the invention-innovation process, with an evident trend in patenting activity.

Universities are now playing a leading role in innovation dynamics and patenting activity (Etzkowitz, 2003; Belenzon and Schankerman, 2013; Quatraro and Scandura, 2020). Empirical evidence stresses their role in enriching the local entrepreneurship ecosystem by stimulating industry R&D and offering a set of specialized services to encourage high-level quality-adjusted entrepreneurship (Jaffe et al., 1993; Tartari and Stern, 2018; Clayton et al., 2018).

Innovation requires sectoral interactions to stimulate the intersectoral knowledge spill-overs. Despite criticisms and concerns on each approach, the methods of research used to address knowledge transfer and innovation dynamics are patent citations, surveys, the number of industry-academia collaborations, co-authorship, co-invention, and research mobility (Bikard, 2018; Crespi et al., 2007; Martínez and Sterzi, 2021; Perkmann et al., 2013; Carayol et al., 2019; Newman, 2004; Lissoni et al., 2011; Breschi and Catalini, 2010; Breschi et al., 2010). Network analysis claim that density and heterogeneity, rather than the number of partnerships, are central to examining knowledge flow and complexity (Gittelman, 2007; Walsh et al., 2016; Malerba and McKelvey, 2020; Stephan et al., 2019). Variation, centrality and good connection in a network composition determine the performance outcomes (Cohen and Levinthal, 1990; Cassi et al., 2008; Lamperti et al., 2020).

We still partially know what factors drive collaboration among innovative actors and sectors. A vast stream of literature investigated the presence of *small world structural* properties in invention networks in technological fields (Watts and Strogatz, 1998; Lissoni et al., 2011). Another body explored the role of *social, cognitive, and geographical proximity or (spatial clustering)* in inventors and co-patenting networks (Crescenzi et al., 2016). *Proximity* plays a role in stimulating face-to-face interactions, specialized knowledge exchange, and networks creation to encourage innovation commercialization (Nesta and Saviotti, 2005; Gittelman, 2007; Lindelöf and Löfsten, 2004). Knowledge spill-overs tend to cluster geographically, although *geographic proximity* seems to have a slight effect on the probability of knowledge flows among inventors (Breschi and Lissoni, 2001, 2004, 2005; Breschi et al., 2010; Singh, 2005; Jaffe, 1989). Our knowledge of the formation of a collaborative patent network remains incomplete. We thus explore whether the adoption of new domestic institutional settings correlates with new trajectories and the emergence of new innovative actors in the co-patenting network.

3 Data

3.1 Our Dataset

The data used in this paper are extracted from PATSTAT (Autumn 2020 and Spring 2021). This database collects scientific and technical information to investigate industry and institutions performance across countries. Besides covering 40 intellectual property authorities, it includes more than 100 million patents applications and publications made between 1978 and 2020.

For our analysis, we preferred to exclude patents listed in USPTO. Some confusion originates from the different patent examination procedures between the USPTO and the EPO (Breschi and Lissoni, 2004). In the former case, applications may come only from individuals (*inventors*). Once granted, they may assign their patents to a legal person (*companies or organizations*). Conversely, the European Patent Convention allows legal persons to apply for patents and help us to distinguish between inventors and applicants more clearly. Moreover, PATSTAT subdivides patents into five different sectors (*Chemistry, Mechanical Engineering, Electrical Engineering, Instrument, and Other*) and 35 technological fields, classifying innovation branches.

An EPO PATSTAT patent contains precise information on both the inventor and applicant, filing year, sector, backward and forward citations in scientific and non- literature (De Rassenfosse et al., 2014; Pasimeni, 2019). Existing research agrees in considering patent data a reliable source of information to measure innovation, social distance, technological relatedness, technological competencies (Breschi et al., 2010; Dibiaggio and Nesta, 2005).

In our paper, we consider all the *co-applications patent data* included in *Chemistry, Mechanical Engineering, Electrical Engineering* and the respective 27 technological fields, with filing year in the time interval 1978–2018, all listed in Table 1.

Table 1: Summary of the selected technological sectors and technological fields for the *co-application patent data*

Technological Sector	Technological Field	
Chemistry	Basic Materials Chemistry	Macromolecular Chemistry, Polymers
	Biotechnology	Materials, Metallurgy
	Chemical Engineering	Micro-Structural and Nano-Technology
	Environmental Technology	Organic Fine Chemistry
	Food Chemistry	Pharmaceuticals
		Surface Technology, Coating
Electrical Engineering	Audio-Visual Technology	Electrical machinery, apparatus, energy
	Basic Communication Processes	IT methods for management
	Computer Technology	Semiconductors
	Digital communication	Telecommunications
Mechanical Engineering	Engines, pumps, turbines	Other special machines
	Handling	Textile and paper machines
	Machine tools	Thermal processes and apparatus
	Mechanical elements	Transport

Source: PATSTAT – EPO Worldwide Patent Statistical Database 2020 & 2021

Our choice derives from several methodological considerations. First, *co-application data* provide a great source of information to examine technology transfer and the existence of an R&D contract (Breschi and Lissoni, 2004; Martinez and Bares, 2018; Stephan et al., 2019). For instance, recent studies employed *joint patents* to measure the technological development trends in the university-industry collaboration (Chang, 2017). Similarly, we use *co-application data* to investigate the connectivity among innovative actors and their centrality in co-patenting networks. Then, most previous studies have focused on biotechnology, pharmaceuticals and nanotechnology but are usually limited to a specific national or institutional environment, mainly *academic inventors* (Powell et al., 1996; Nesta et al., 2004b; Nesta and Saviotti, 2005; Nesta and

Dibiaggio, 2003; Bonaccorsi and Thoma, 2005). Last, empirical literature provides evidence that universities and PROs are most likely to be found in *science-intensive and science-oriented technological fields* due to the importance of public research in inventive activity (Lissoni et al., 2011, 2013).

We initially obtained a dataset that included 39,385 French patents, of which 25,443 *co-owned ones*, with 6,299 applicants. We then proceeded with an accurate data cleaning. First, we excluded *non-cooperative applicants* and *incomplete patents*, whose sector was unknown. Secondly, we restricted our analysis to a significant sample of applicants appearing, at least for two years, at least in five patents. Thirdly, we concluded with a manual name harmonisation to capture all name variants (e.g., spelling and typing errors) and track the change of French universities[2]. Besides avoiding double-counting of the same patent applicant, this approach helped us improve data accuracy and quality and reduce any margin of error. The cleaning procedure returned 37,077 French patents, of which 23,522 co-owned by heterogeneous actors, with 896 different applicants. For each application, we retrieved information falling into two broad categories:

- **Patent data** (application id, application number, number applicants, number inventor, application filing year, technological sector, technological field, granted, documentation database family size, number citing documentation database family)

- **Applicant data** (personal name, nuts label, person country code, personal sector)

At last, we classified the institutional affiliation of applicants into seven categories: ***Company (French), Foreign Company, University (French), Foreign University, Individual, Hospital and Public Research Organizations*** [3].

Our methodological approach finds justification in the legal and institutional setting of the French innovation system to address the issue of technology transfer and patent ownership. Public Research Organizations (PROs) indicates a non-university and non-enterprise research-focused public entity, performing both basic and applied research, and where the government has a strong influence. Contrary to Lissoni et al. (2011), who considered only CNRS and might

[2]Since 2009 the French Ministry of Higher Education, Research and Innovation encouraged "university regrouping" to strengthen links between universities and research poles, as part of the Investments for the Future Programme (PIA), led by the General Secretariat for Investment. Public higher education establishments themselves enact the fusion by adopting *ad hoc* decrees, giving proof of the autonomy gained.

[3]In our paper, we place greater emphasis on the *applicants* rather than the *inventors* to investigate the interactions among the different institutions considered and the evolution of patent ownership distribution.

have underestimated the number of PROs patents, we included all the public research organizations (e.g., CNRS, ANR, and INSERM).

Although we are aware of the role and contribution of *academic inventors* (e.g., researchers and professors) in developing the idea in a patent, we restricted our empirical analysis to the university-owned patents, namely the ones in which universities or their technology transfer offices (TTOs) appear as *applicants* (owner). Although university-owned patents do not fully show the wealth of contributions made by the professors as *inventors*, we still believe them to be a strong indicator of the role of universities in innovation and crucial in uncovering previously ignored evidence. University-owned patents may help us estimate how cultural and regulatory differences on the attribution of IPRs impact the patent ownership distribution[4].

The distribution of patent-ownership across the 37077 French patents, in the *psn_sector* and *technological_field* selected, is highly skewed, as Table 2 shows.

Table 2: Summary Statistics overall period (1978-2018)

psn_sector	Nb.	Share of applicant (%)	Share of applications (%)
Company	426	52.01	45.99
PROs	108	14.29	57.83
Hospital	5	0.56	1.08
Individual	13	1.56	2.38
University	102	11.61	15.99
Foreign_Univ	29	3.35	1.09
Foreign_Comp	132	16.63	20.36
Total	815	100.00	144.71

Note: The 102 French universities represent 11.61% of applicants and are involved in 15.99% of French patents. Total *share of applications* is superior to 100% as some applications imply several types of actors. In average we count 144.71 applicants for 100 patents.

Some of our statistics confirm what previous studies discovered. First, the ownership pattern differs across sectors and actors (Lissoni and Montobbio, 2015). Secondly, *French companies* play a fundamental role in co-patents (52%), contrary to *Foreign companies* (16.6%). Third, the rate PROs-owned patent is extremely high, thus positioning as the second most important

[4]Contrarily to the *university-owned patents*, existing literature defines *university-invented patents* through the affiliation of their inventors with a university, e.g. a member of a university faculty, independently whether the university is or not the patent applicant. In this regard, the number of universities-invented patents is much higher than the number of patents owned by universities.

French co-patenting actor. This result is indicative of the French research system where PROs have always played a central role. Contrary to the expectations, *French Universities* represent only 11.6% of the patents applicants while *Foreign ones* only 3.3%. *Hospital* records the lowest share (0.56%), probably due to the specific research scope and limited application sectors.

Table 3 summarizes some basic statistics we obtained dividing patents by temporal breaks. It reports the evolution of the relative share of types of actors in the French patenting system. Among noticeable trends, the increasing role of universities is worth to be detailed.

Until 1999, PROs and private companies were the leading actors. Conversely, only 32 French universities appear as significant patenting institutions (8.91%), involved in only 2.50% of total patents. With the adoption of the Innovation Act (1999), French universities increased their patenting performance. The number of French universities patenting tripled (*extensive margins*), while the number of French university patent applications increased far more rapidly than any actor (*intensive margin*). The engagement of French universities co-patenting applications shifted from an initial 2.50% to 27.6%. In absolute value, they witnessed an increased ratio of over 14 times: patents moved from 326 patents applications in the initial period to over 4,600. Yet, the total number of patents applied multiplied only by 1.28%.

Looking at the other actors, private companies (*French and foreign ones*) are losing ground. The share of French companies' applications shifted from 56.28% to 37.57%, with an evident decline in the share of applicants. On the contrary, the historical central position of PROs has not been harmed by the rise of French universities, with their involvement in over two-thirds of French co-patents. This result may depend on the increasing average number of actors' sectors by co-patents (from 1.35 to 1.53). Our data seem to highlight a visible trend: co-patenting is increasingly *inter-sector* rather than *intra-sector*.

Table 3: Summary Statistics : decomposition by time periods

1978-1999

psn_sector	Nb.	Share of applicant (%)	Share of applications (%)
Company	197	54.87	56.28
PROs	50	13.93	45.45
Hospital	2	0.56	0.15
Individual	8	2.23	3.61
University	32	8.91	2.50
Foreign_Univ	12	3.34	0.22
Foreign_Comp	58	16.16	26.95
Total	359	100.00	135.15

2000-2007

psn_sector	Nb.	Share of applicant (%)	Share of applications (%)
Company	192	49.23	46.72
PROs	42	10.77	56.89
Hospital	2	0.51	0.72
Individual	2	0.51	2.45
University	66	16.92	13.94
Foreign_Univ	18	4.62	1.39
Foreign_Comp	68	17.44	20.61
Total	390	100.00	142.73

2008-2018

psn_sector	Nb.	Share of applicant (%)	Share of applications (%)
Company	263	45.90	37.57
PROs	87	15.18	68.01
Hospital	4	0.70	2.01
Individual	6	1.05	1.38
University	101	17.63	27.67
Foreign_Univ	27	4.71	1.58
Foreign_Comp	85	14.83	15.08
Total	573	100.00	153.29

4 Methodology

4.1 Building the patent collaboration network

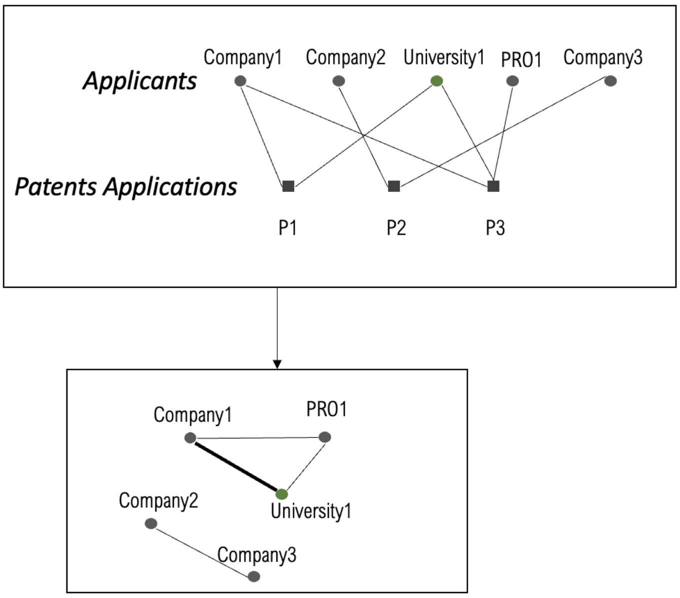
Many studies have used network analysis to evaluate technology developments, innovation dynamics and country-technology trends. A growing school of research investigates the impact of knowledge network structures on innovation outcomes and the position of actors in the network space. A dense cluster may exist through links, where some occupy a privileged and central position depending on the nature of the involvement and the positional strength, showing *"small worlds"* properties (Powell et al., 1996; Huggins et al., 2020; Lissoni et al., 2013). In particular, there has been an increasing interest in the role of universities and other public research institutes in knowledge transfer, the factors determining these flows, and output commercialization (e.g., collaborative research, consultancy, patenting) (Perkmann et al., 2013).

Patent network analysis is a technique widely employed to map invention and innovation networks, with two policy implications. Besides working as a reliable policy indicator, this technique captures the evolutionary patterns of technology centrality and the trends of technology developments (Chang, 2017). This methodology represents in our paper the framework to construct a *co-patenting network collaboration* and assess the centrality of French universities. The goal is to observe the progressive development and the restructuring of innovation dynamics after significant institutional changes in France, respectively 1999, 2006 and 2007. The last decades have witnessed remarkable changes resulting from sectors transformation. Research institutes, technology institutes and university laboratories have become more differentiated but more mixed with industrial research.

After restricting our analysis to the most significant French patents, in line with our data cleaning and classification, we followed the methodology employed in Borgatti and Everett (1997). We initially rebuild a *bipartite (or affiliation) network* and associate each patent application with the applicants' sectors. Then, we project our *bipartite network* in the actors' dimension, where applicants are linked based on their collaborations frequencies in patents filings, as Figure 1 shows[5].

[5]This step was done using the *nw_projection* Stata algorithm, available on SSC – Boston College of Economics (Joyez, 2020)

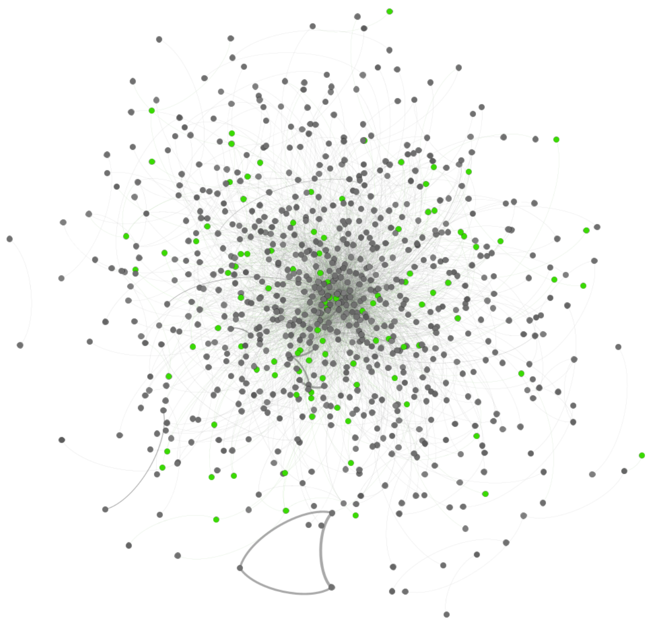
Figure 1: Initial affiliation data and its projection in the applicants' dimension



Note: Figure 1 visually describes the network we recreate in our paper. Company1 and University1 are linked with a weight of 2, as they collaborate in two patents applications (P1 and P3). On the contrary, Company2 and Company3 form a distinct sub-network as they only collaborate with each other.

We obtained a weighted undirected network with 896 nodes (applicants), projected over the time span 1978-2018, where green dots denote French Universities, as Figure 2 shows.

Figure 2: Full French co-patenting network (1978-2018)



Note: Figure 2 presents the French co-patenting network as a whole, with the grey nodes representing firms and other organisations and the green nodes university. Some universities occupy highly central positions within the network and have high rates of relational involvement in patenting activities based on their links with firms and other organisations that are themselves highly central. Others are more distant from the centre and are generally less well connected to the network.

Following the methodology employed in Barthelemy et al. (2003) on the reverse of the disparity index, the network reveals a high disparity among the frequency of collaboration and a very low density. Only 1% of potential edges appear in our network. Additionally, with an average of 6.5 neighbours with which innovative actors apply for patents, the network collaboration shows greater diversity than expected.

4.1.1 Centrality and French universities in the network

The importance and prominence of an actor in innovation diffusion lies in the number of patent applications and interactions with other applicants (Crescenzi et al., 2016; Lamperti et al., 2020), generally captured by *node centrality* in a network. Several works insist on how this centrality feature of a node may emerge as the solution of a cooperative game between individual actors (Tarkowski et al., 2017).
The focus on centrality indexes in innovation and patenting networks is not new in the literature, as shown in Cassi and Plunket (2015) and Huggins et al. (2020) that attempt to seize the factors that determine the central position of universities in those networks. In general, several centrality indexes have been developed according to the dimension conveyed behind the idea of being central. While the most common *Degree, Closeness and Betweenness Centrality* were formalized by Freeman (1978) respectively insisting on direct connectivity, average distance, and shortest path between nodes, they are designed for *unweighted networks*. Their generalization for weighted networks, like ours, is not straightforward (Opsahl et al., 2010).
For our purpose, we adopt a more sophisticated, although less intuitive measure, developed by Bonacich (1987), to evaluate the most influential nodes: the *eigenvector centrality*. Besides showing the number of connections that a node has with other nodes, as *degree centrality* would, it rests on a simple assumption: connections to more important nodes should be valued more than equal links to less relevant nodes. By looking beyond the first-order linkages, the *eigenvector centrality* captures information from the whole network. In a disassortative network like ours, nodes with many links tend to be connected with lowly connected ones. This index has been widely applied in network literature to assess power, the structure of inter-organizational networks, and the role of an individual or an entity in a social network (Bonacich, 1972; Borgatti and Everett, 2006). In Borgatti et al. (2018), *eigenvector centrality* is interpreted as a measure of popularity, suggesting that a node with a high index is connected to nodes that are themselves well-connected. Moreover, it easily adapts to a weighted network

like ours, where different edges' weights indicate the frequency of co-patenting collaboration by taking the weighted adjacency matrix, as pointed out in Newman (2004). Therefore, we will rely on weighted eigenvector (WEV) centrality to keep the information on collaboration's frequencies and capture higher-order connectivity rather than direct links.

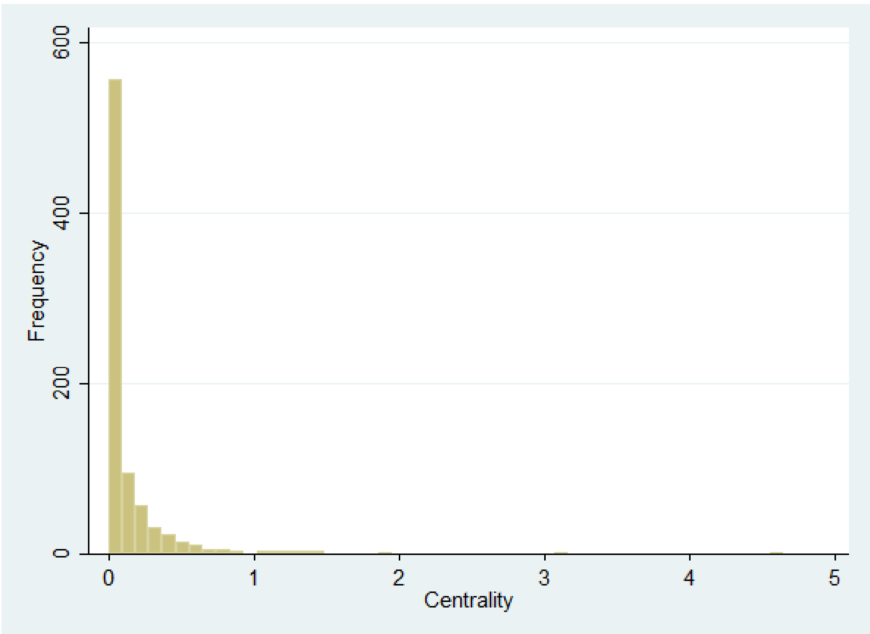
Mathematically, we can define the eigenvector centrality score for a given network as follows:

$$c_i = \lambda^{-1} \sum_j M_{ij} c_j \tag{1}$$

Where λ is a constant, such that the vector $c_{1...,N}$ is an eigenvector of the square matrix of edge's weights M_{ij}. We then normalized the centrality score as a percentage share of the total to ease the comparison across networks.

Figure 3 describes the distribution of our *eigenvector centrality*, which has an expected high concentration at the beginning of the distribution. This trend occurs in *real-world networks*, where centrality is largely unequally distributed across actors, and especially in universities' collaborative patent networks, which exhibit a *small-world structure* (Lissoni et al., 2013; Watts and Strogatz, 1998). It thus justifies the choice of using the log-transformation of centrality.

Figure 3: Histogram of normalized centrality index (1978-2018)



Note: Centrality may deal with the applicants in top central positions. Over 1978-2018, the three most central innovative actors are CNRS (4.6% of total centrality), INSERM (3.11%) and CEA (1.93%). The two following are two universities: Paris-Sud and Paris-6. Our results are in line with Lissoni et al. (2011) who found out that academic and CNRS are highly central actors in French inventors' networks.

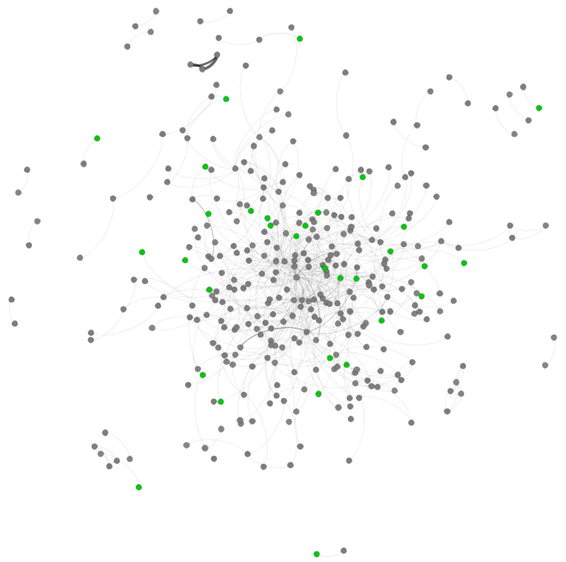
For completeness, we perform a robustness check using Freeman (1978) *betweness* centrality of co-patenting actors as a secondary measure of centrality. *Betweenness centrality* does not reflect nodes' connectivity. On the contrary, it reflects the nodes frequency on the shortest paths between two applicants. It seems to capture the property of controlling information flows within a given graph and helps identify who plays the role of broker or gatekeeper (Lamperti et al., 2020). The results can be found in the Appendix A. This betweenness centrality index shows a positive correlation with *eigenvector centrality*, but with a low coefficient of 0.349, significant at 5%. This moderated correlation certainly comes from the fact that *betweenness centrality* does not consider edges' weights, as explained above. This view helps us justify our choice of focusing on *weighted eigenvector centrality*.

4.1.2 Evolution of French universities' position

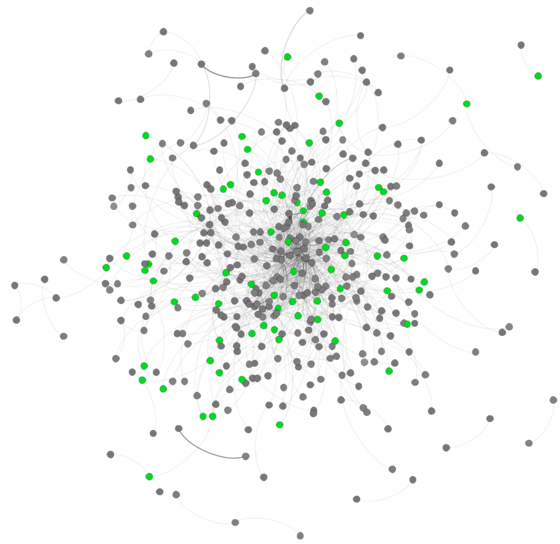
The overall network, previously depicted, is instructive but weak in investigating the evolution of French universities in *co-patenting*. To assess the impact of French policy interventions on their centrality in patents collaborations, we divide the network into three temporal breaks characterizing legislation changes, as shown in Figure 4.

Interestingly, the network shows a significant and observable trend in the three temporal breakdowns. Over the last 40 years, the collaborative patenting network gained in size (*number of actors*), connectivity and density, as Table 4 summarizes.

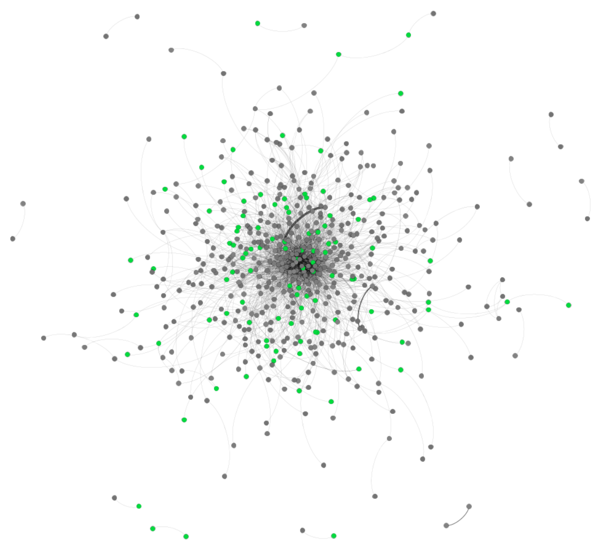
Figure 4: French co-patenting network in temporal breakdowns



(a) 1978-1999



(b) 2000-2007



(c) 2008-2018

Note: Figure 4 presents an illustration of the core sub-network, divided in temporal breakdown reflecting the legislative changes. Grey nodes denote firms and PROs, and the green nodes university. Across the three figures, there is an evident trend for the networks: it becomes denser, more connected and concentrated. A group of universities act as open innovators, given that they possess significant links (*high density* and *high connectivity*).

Table 4: Network Index

Network index	1978 - 1999	2000-2007	2008-2018
Nodes	359	390	573
univ	32	66	101
Density	0.009	0.010	0.015
Centralization (weighted)	0.295	0.295	0.378
Diameter	10	10	9
Average shortest path	3.84	3.25	2.79
Average degree	2.5	3.68	8.02
Disparity	0.685	0.644	0.483
Average centrality	0.279	0.256	0.174
univ	0.205	0.531	0.434
companies	0.263	0.122	0.076
Pub. Res. Org.	0.630	0.791	0.305
Top ranked university	Univ. de Strasbourg	Univ. Paris Sud	Univ. Paris 5
rank	12	6	4
Nb of universities in top 50	3	22	30

Note: With regards to *weighted centralization*, the authors' computations are based on the *Strength Centralization Index* developed in Joyez (2017).

The gain in connectivity reduced both the *average shortest path* and the *network diameter*. Although the average production of co-patents has not increased significantly, the average number of co-patenting actors (*average degree)* shifted from 2.5 to 8. This increase may depend on the increasing number of collaborations, with a different average centrality for the actors. More in detail, universities started playing a more central role in the co-patenting system, contrary to companies and public research organizations that are witnessing a *decentralization trend*. Interestingly, one of the most remarkable results to emerge from the Network Analysis is the increasing number of universities in the top-50, with some in a top-ranked position. While the average centrality of applicants decreased by 37% due to more actors involved, both PROs and universities show an inverse U-shape. An initial increase in centrality occurred between 1999 and 2007, with a marked slowdown from 2007-on. Yet, its magnitude is smaller for universities than the average trend.

To assess the change of universities' position in the network, we compute the *extensive and intensive margins* of universities' patents applications. We explore the number of universities involved in co-patenting and how many patents they have produced over time. From our estimates, the number of universities involved and the average centrality more than tripled. In the first period (1978-1999), only 32 French universities were involved in 256 applications with an average centrality, $\sum c_i^U$, the aggregate centrality of French universities amounting only to 6.57%. In the second period (2000-2007), the number of French universities doubled, shifting to 66 and being involved in 902 patents, thus increasing the aggregate centrality, $\sum c_i^U$, up to 35.02 %. Last, in the third period (2008-2018), the number of French universities reached 101, being now involved in 6203 patents, with an aggregate centrality, $\sum c_i^U$, equal to 43.80%. The rise in both margins of universities' co-patenting activities translates into the surge in centrality, although not proportionally. Centrality is indeed normalised to account for the relative importance of third applicants.

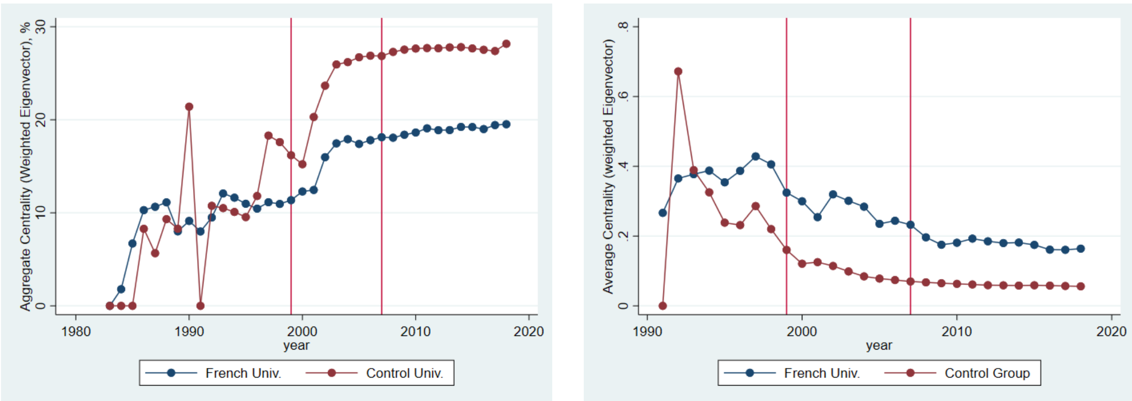
4.2 Estimation strategy

We apply a Difference-in-Differences (DID) estimation strategy to identify the potential causal relationship between the increasing centrality of French universities and new policy interventions (our exogenous events) (Lechner et al., 2011; Wooldridge, 2015; Stuart et al., 2014). The existing empirical economic literature widely explored the benefits of this methodology to evaluate the effect and implementation of policies. Our strategy consists in running a quasi-experimental research design and conducting a cross-sectional treatment-control group. We aim at comparing the differences in changes before and after policy interventions between French Universities (our *treatment group*) and a proper *control group*. The latter must be a similar entity, not affected by the same French legislation dynamics, and whose data are likely available (Fredriksson and de Oliveira, 2019). The DID estimator is based on the *"parallel trend assumption"*: *treatment* and *control group* should have a similar trend in the absence of any treatment, thus providing unbiased effect estimates (Abadie, 2005; Duflo et al., 2007).

Previous studies exploited DIDs to examine the impact of regime shifts, like the abolition of the *Professor's Privilege*. For instance, Czarnitzki et al. (2015) explore the changes in patenting and the institutional structure in the German research system. On the contrary, Hvide and Jones (2018) examines its impact in Norway by breaking up the sample into pre-and post-periods and comparing start-ups and patenting rates inside and outside the university sector. Recently, Martínez and Sterzi (2021) investigated its impact on the technological importance and value of university-owned patents.

In our paper, we initially focus on two neighbouring countries: Germany and Italy. As we will discuss in-depth in the following section, our choice finds justification on two main grounds. First, they are among the main contributors to PATSTAT and the most developed European economies, like France. Secondly, the evidence on the impact of innovation policy implemented in these countries to encourage university patenting is controversial. To assess the *parallel trend assumption*, we plot in Figure 5 the yearly evolution of aggregate centrality and average centrality of all French universities, along with the one from the control group.

Figure 5: Evolution of aggregate centrality of French universities and control group (Germany and Italy)

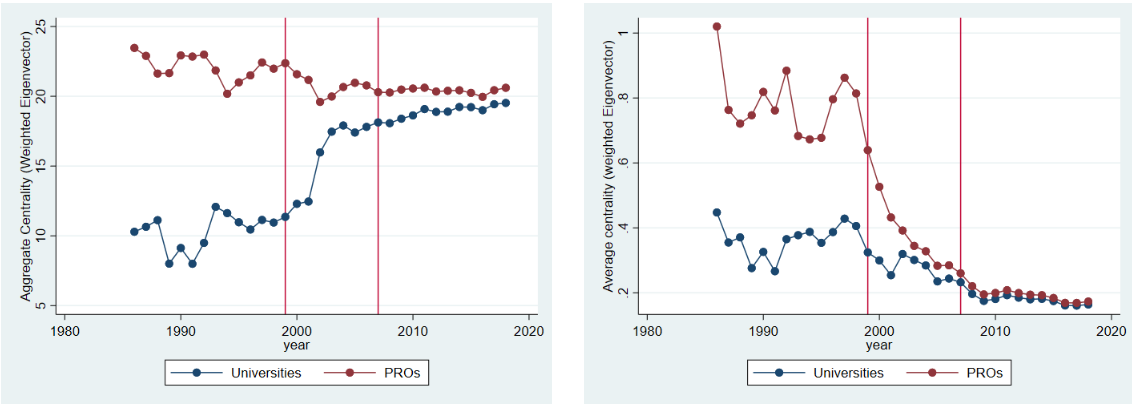


Note: 3 years moving average of aggregated (left-panel) and average (right-panel) centrality of Universities, in France and the Control group (Italy and Germany).

Several insights may be learned from this figure. First, French Universities lag behind their European neighbours in terms of centrality in their national patenting system. Second, since the 1990s, the two groups seem to follow a similar trend, despite the legislative change in France. Last, the dynamics of French universities appear to be more volatile, and inflexions points appear around the legislative changes, which strengthens our assumption of an impact of institutional changes in university patenting patterns.

For completeness, we perform a robustness check employing a second control group: French Public Research Organisations (PROs). We consider this category for two reasons: first, they are not affected by the legislation changes for universities; second, they are the closest actor in the French research system, sharing a non-profit research objective, as well as public ownership. Although the centrality of two actors in the same network is partly rival, Figure 6 shows that the adjustments are mostly done on third-actors margins. A somehow parallel and constant trend of the aggregate and average centrality exists before the treatment, with a neat break after the adoption of *Innovation Act* (1999), reducing the lag French Universities had compared to PROs in the patenting network.

Figure 6: Evolution of aggregate centrality of French universities and control group (French PROs)



Note: 3 years moving average of aggregated (left-panel) and average (right-panel) centrality of Universities, in France and the Control group (Italy and Germany).

To confirm these hypotheses, we run the linear parametric DID model, as expressed in equation (2) to estimate the specifications for the *treated and control group*:

$$\begin{aligned} Cent_{it} = \beta_0 + \beta_1 FrenchUniv_i + \beta_2 LegChange_t \\ +\beta_3 LegChange_t * FrenchUniv_i + \beta_4 Controls_{it} + \epsilon_{it} \end{aligned} \quad (2)$$

where $i = 1$ .., N refers to innovative actors and $t = 1978$ ... 2018 indexes time. More in detail, $Cent_{it}$ measures the centrality score of each actor at time t (*before vs. after legislative change*). $FrenchUniv_i$ is a dummy with β_1 capturing the trend in the treated group (compared to foreign universities or PROs controls). β_2 captures the average effect of the law adoption for all actors. The DID estimate equals the estimated coefficient on the interaction of a treatment group dummy and a post-treatment period dummy. Hence, β_3 captures the hypothetical differentiated effect of legislation changes on French universities contrasted with control groups. The difference in centrality may depend on some key characteristics differing between the groups that may influence the outcomes studied or the heterogeneity in outcome dynamics. Therefore, we include a vector of coefficient capturing fives control variables, β_4, to identify variation within-group change. Although they help detect the heterogeneity effect, every additional variable makes the support assumption harder to fulfil, as previously noted (Goodman-Bacon, 2021; Lechner et al., 2011). Therefore, these variables must be exogenous and unaffected by the treatment to avoid any bias:

- ***Pat_number***, which indicates the number of patents produced by applicants;

- ***Pat_famsize*** which indicates the average patent family size by applicants (i.e. number of countries where the same invention is patented) and is used as a proxy of the economic value of the patent;

- ***Pat_citation***, which refers to the number of forwarding citations at the family level to avoid home-bias and normalizes duplicated citations thus providing a more encompassing view of the patents' impact as a qualitative proxy (Bakker et al., 2016; Tetsuo et al., 2018);

- ***Pat_shgrant***, used a proxy of novelty, which refers to the share of granted applications;

- ***Pat_diver_tech***, which indicates the number of technological fields where an applicant appears;

The novelty of the paper consists of the analysis of two different legislative shocks and their role in sustaining and encouraging the centrality of French universities in the French patenting innovation system. The basic DID estimation strategy has data from two groups and two time periods. To control for systematic differences between the control and treatment groups, we need two years of data, one before the policy change and one after the change. Thus, our sample classifies four groups: the control group (before and after the change) and the treatment group (before and after the intervention). In our case, since we study two different legislative reforms, with two control groups, our main specification explained in Equation 2 is run four times. We expect the legislative changes to show up in a positive coefficient. We suppose that a positive correlation exists with the centrality of French universities.

4.3 The choice of Italy and Germany as control group

The legislation governing patent ownership of publicly funded inventions has been rather heterogeneous in Europe in the 1980s and 1990s, even though it began to converge to a more homogeneous IP regime from the early 2000s (Martínez and Sterzi, 2021). As in the case of France, also Italian Universities underwent a radical reform process in these years, although it emerged as a real outlier. Contrary to the European trend, Italy introduced the *Professor's Privilege* or *Academic Privilege* in 2001, witnessing a change in the university IP legislation: university professors and researchers obtained the right to grant the ownership of academic inventions, rather than giving it to the university. The belief was that profits would have been higher for individual inventors since universities lacked the competencies to promote patents. The impact of this law remains controversial. Existing studies stress that its introduction did not increase patenting ownership. Italian universities were initially reluctant in complying with the *Academic privilege* lacking incentives to manage inventions developed in their labs. Moreover, national legal changes granting universities control over their faculty activities regarding both inventions and autonomy on financial resources and IPR regulations neutralized *the Professor's privilege* making it ineffective, as explored in many studies (Lissoni et al., 2013; Sterzi et al., 2019). Although Italian academic patents increased between 1996-2007, and the shift to academic inventors occurred in the same years, the rise of Italian university ownership is attributed, significantly albeit not exclusively, to the autonomy gained by the institutions. Universities explicitly introduced IP regulations on their faculty inventions and funding strategies, as explored in Baldini et al. (2006, 2010). This empirical evidence shows that patenting activities tripled in those universities adopting an internal IPR regulation since 1993 (with higher performance in large universities and clustered in Northern Italy). More in detail, patent applications increased already with the publication of the 1996 Law, which gave universities, among other things, complete autonomy in the management of technology transfer activities and allows them to retain the surplus generated by research commercialisation. The increased patent ownership stimulated other incentives: an influence on university finances through IP licensing and a higher evaluation in technological excellence.

In 2002, Italian universities created the Italian Network for the Valorisation of the University Research (NetVal), which aims at improving protection, research production, and commercialisation besides universities-firm collaborations. By the end of 2004, more than 60% of the Italian universities joined it. Meanwhile, modification on the pre-existing *Academic Privilege* occurred in 2005, narrowing this privilege to results fully funded by university resources. Inventions, partially privately financed or from a research project supported by a public institution different from the inventor's, were excluded. Besides increasing complexity and uncertainty on IPR on jointly private-public projects, it did not provide any incentives to universities to manage inventions developed in their labs (Baldini et al., 2010).

At the European level, some countries strengthened institutional ownership controls and made commercialisation and technology transfer their principal missions by adopting new IP regulations and granting the invention rights to universities. Germany abolished the *Professor's*

Privilege in 2002 to push university researchers to disclose their inventions and grant ownership to the university, which became in charge of the whole patenting process. The underlying reasons were motivated by the apparent success of the US Bayh-Dole Act and the idea that individual researchers would be unwilling or unable to pursue the commercial application of their ideas (Hvide and Jones, 2018; Martínez and Sterzi, 2021). The policy goal aimed at commercialising publicly funded research results (that would have otherwise remained unexploited), increasing patenting of university-invented technologies, creating employment through academic spin-offs, and eliminating barriers to collaborative research (Von Proff et al., 2012)[6]. If effective, this policy would have worked as an indicator of successful university-firm transfer. Its impact remains controversial with different results. A relevant stream of empirical literature points to the negative influence of the abolition of the *German Academic Privilege*. The policy change did not increase university-invented patents and patenting activities, despite the ownership shift from individually-owned patents (*inventor-ownership*) to the university-ownership model. For instance, Czarnitzki et al. (2015) show that the volume and quality of inventions patented by university professors decreased in the medium-run. Although the university became a relevant actor in patenting, the benefits to institutional owners (patenting professors) declined due to high costs, risks and insufficient incentives to pursue profit-oriented research. Likewise, Von Proff et al. (2012) observe a greater propensity for German Researchers to assign patents to their university after the 2002 Reform. Additional findings in Martínez and Sterzi (2021) are consistent with the previous studies: a decline in the technological importance and lower quality in university-owned patents, despite an increase in the average technological quality of academic inventions owned by companies.

In the same years, the German government launched the *Knowledge Creates Market Programme* to set up new infrastructures to stimulate university-industry technology and innovation transfer and overcome the *European Paradox*. It thus established Regional Patent Valorization Agencies (PVAs) to provide subsidies to university-specific TTOs, and support universities in the commercialization activities: screening inventions, finding industry partners, promoting collaborations, and launching faculty start-up companies. Yet, this policy reform decreased overall university technology transfer without effectively implementing university start-ups and patents' volume (Czarnitzki et al., 2015; Von Proff et al., 2012; Czarnitzki et al., 2016).

[6]Before its abolition, the *Professor's Privilege* allowed university researchers and professors to own the rights of their inventions, thus deciding whether to patent or not and how to commercialize their discoveries. On the contrary, researchers in public research organizations, such as Max Planck, Frauhofer and Helmholtz, were not affected. Germany had a unique division of labour between universities and PROs.

5 Results

5.1 Differences in Differences

Table 5 reports the results of the DID estimation strategy detailed in Eq. (2) to examine the causality link between the impact of new policy initiatives on the centrality of French universities in the collaborative patents networks. The treated variable is a dummy variable tagging French Universities, in contrast to foreign ones (in Italy and Germany).

Column (1) reports the estimation for the impact of the Innovation Act (1999) (*LegChange1*), while Column (2) details the impact of the second set of legislative change (2006 and 2007 laws, *LegChange2*). A positive and significant interaction term between the treated and treatment variables would indicate a beneficial impact of legislative change on the centrality of universities in patenting collaborations. On the contrary, a negative coefficient would suggest that the legislative change reduced the centrality of French Universities as opposed to the control group of universities abroad. A null or non-significant interaction term would point out that we fail to identify any impact of the change in the institutional framework into universities' position on the collaboration network.

The interaction term displays a positive and significant result for the first period, corresponding to the adoption of the Innovation Act (1999). This legislation change seems to have a considerable impact on the relative importance of universities as patenting collaborators, with an increase of their average log centrality of +2.49 points, all other things being equal. For this first period, only the quantity of patents applied by universities plays a significant role in boosting their centrality, with an elasticity of 0.76.

Concerning the second-period break, Column (2), we find a negative and significant impact of the legislative change upon the relative centrality of French universities. This negative shock mostly annuls the centrality gain fostered by the 1999 Law, with a drop of -2.44 points, while the quantity of patents applied for still boosts the applicants' centrality. These results on centrality estimation at the university level are, in some measure, in line with the aggregate picture contrasting French universities with the universities in the neighbouring countries (Figure 5). We observe a catch-up of French universities in the early 2000s that we attribute to the 1999 Innovation Act, while a gap widens after the laws adopted from 2006-on.

Table 5: Differences in Differences model. Control group : Universities abroad

	(1) WEV Centrality (log) 1983-1999	(2) WEV Centrality (log) 1999-2018
FrenchUniv.	0.217	2.642*
	(0.21)	(1.75)
LegChange1	-0.661	
	(-1.26)	
FrenchUniv.*LegChange1	2.492***	
	(3.75)	
LegChange2		1.66***
		(6.09)
FrenchUniv.*LegChange2		-2.447***
		(-8.33)
pat_number (log)	0.756***	0.855***
	(1.88)	(5.38)
pat_famsize (log)	0.545	0.334
	(0.79)	(0.77)
pat_citations (log)	0.392	-0.093
	(1.08)	(-0.52)
pat_divtechn (log)	0.390	0.116
	(0.73)	(0.37)
pat_shgranted (log)	0.191	-0.139
	(0.19)	(-0.24)
_cons	-5.532**	-3.334**
	(-2.51)	(-2.65)
N	192	383
adj. R^2	0.861	0.829
NUTS3 Fixed Effects	Yes	Yes

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

To test the validity of such results, we run a similar DID model, substituting the previous control group of neighbouring universities with French PROs. Estimation results obtained using this second approach are reported in Table 6. Column (1) confirms the positive influence of the Innovation Act (1999) on the centrality of French universities in the patents' collaboration network, as also illustrates the catch-up in Figure 6 between period one and period two. However, with a semi-elasticity of 1.204, the boost is still high. On the contrary, the negative impact of 2006-on legislation on the centrality of French universities is no longer observable if compared to French PRO. Indeed, we find a non-significant influence of the second legislative change in this estimation strategy.

Table 6: Differences in Differences model. Control group : French PROs

	(1) WEV Centrality (log) 1983-1999	(2) WEV Centrality (log) 1999-2018
FrenchUniv.	0.522	0.978***
	(1.14)	(2.75)
LegChange1	0.336	
	(0.860)	
FrenchUniv.*LegChange1	1.204**	
	(2.25)	
LegChange2		-0.495
		(-1.48)
FrenchUniv.*LegChange2		0.033
		(0.09)
pat_number (log)	1.199***	0.906***
	(7.16)	(9.52)
pat_famsize (log)	1.108**	1.172***
	(2.11)	(2.99)
pat_citations (log)	0.197	0.0608
	(0.64)	(0.32)
pat_divtechn (log)	-0.873**	-0.441*
	(-2.08)	(-1.74)
pat_shgranted (log)	-1.575***	-1.570***
	(-2.34)	(-3.09)
_cons	-0.813	-0.041
	(-0.61)	(-0.04)
N	177	277
adj. R^2	0.690	0.693
NUTS3 Fixed Effects	Yes	Yes

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Our two approaches agree on finding a positive influence of the Innovation Act (1999) on the centrality gained by French Universities in the patenting network. The impact of 2006-on laws is either negative or null on their centrality. We find more evident results when contrasting the evolution of French universities with the Italian and German ones. The comparison with French PRO's gives less evident results We believe the first strategy to be more accurate being the centrality of French Universities and French PROs (partially) rivals since defined in the same network, although adjustments may occur through third actors. Yet, the centrality of French PROs is less likely to be unaffected by those reforms than one of the foreign universities abroad. The two results converge partially on the positive and significant influence of 1999's Innovation Act over the 2006-2007 set of laws over the universities' centrality.

5.2 Propensity Score Matching

We complement our initial estimation strategy by incorporating kernel Propensity Score Matching strategy (PSM) in our DID following the popular methodology developed by Heckman et al. (1998). Rather than accounting for control variables, this method matches treated and control units according to their propensity score. Each treated unit is matched to the whole sample of control units based on our five control *covariates*, with an individual weight derived from the propensity score. To increase the internal validity of the PSM, we restrict the sample to *common support* of the propensity score for both groups, removing low-quality matches[7].

The combination of DID with PSM is seen as a strong non-experimental study when randomization is not feasible. As pointed out in Rosenbaum and Rubin (1983), balancing scores between treatment group and control group help obtain more meaningful comparisons. Moreover, PSM is specific to handling confounding variables (minimizing selection bias between them) and estimating average treatment effects (ATE)[8] (Stuart et al., 2014; Abadie and Imbens, 2016). Additionally, PSM reduces extrapolation and dependence on the outcome model specification, providing more robust inferences and condensing the set of *covariates* into a scalar summary. We thus estimate the propensity-score matching DID treatment effect as follows:

$$\begin{aligned} Cent_{it} = \beta_0 + \beta_1 FrenchUniv_i * w_i + \beta_2 LegChange_t \\ + \beta_3 LegChange_t * FrenchUniv_i * w_i + \epsilon_{it} \end{aligned} \tag{3}$$

Where w_i is the kernel weight from the propensity score matching.

Table 7 and Table 8 display the result of the PSM weighted DID respectively using foreign universities and French PROs as control groups.

[7] The support assumption implies that the probability of receiving treatment for each possible value is strictly within a unit interval [0,1], as is the probability of not receiving treatment. Once a propensity score has been calculated for each observation, this assumption ensures that a sufficient overlap in the characteristics of treated and untreated units exists to find adequate matches. No inferences about treatment effects can be made for a treated individual for whom there is not an individual comparison with a similar propensity score.

[8] DID present some drawbacks in the selection: the control and treatment groups may change in composition over time, affecting their trends over time, (*across time bias*), or in the group composition itself (*across group bias*).

Table 7: Propensity Score Matching DID. Control group : Foreign Universities

	(1) WEV Centrality (log) 1983-1999	(2) WEV Centrality (log) 1999-2018
FrenchUniv.	1.183***	2.379***
	(3.17)	(7.95)
LegChange1	0.436	
	(1.16)	
FrenchUniv.*LegChange1	2.504***	
	(4.56)	
LegChange2		2.673***
		(8.76)
FrenchUniv.*LegChange2		-2.037***
		(4.76)**
_cons	0.211	0.633***
	(0.80)	(2.99)
N	76	242
adj. R^2	0.63	0.34

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8: Propensity Score Matching DID. Control group : French PROs

	(1) WEV Centrality (log) 1983-1999	(2) WEV Centrality (log) 1999-2018
FrenchUniv.	0.367	1.162***
	(0.89)	(3.25)
LegChange1	0.593	
	(1.05)	
FrenchUniv.*LegChange1	2.151***	
	(2.99)	
LegChange2		0.387
		(1.05)
FrenchUniv.*LegChange2		0.296
		(0.58)
_cons	1.062***	1.787***
	(3.62)	(7.07)
N	104	169
adj. R^2	0.37	0.16

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The results of the DID estimation incorporating kernel propensity-score weights are in line with the initial DID strategy, with the interaction coefficient of similar signs, significance and magnitude, especially when considering the foreign universities in Italy and Germany as the control group. These results confirm a positive and significant effect of the Innovation Act (1999) on the centrality of universities in the co-patenting network. They have become more prominent actors in scientific knowledge and innovation diffusion through more co-patenting applications, with a broader set of (more relevant) partners. The second set of reforms in 2006-2007 is shown to have either an adverse effect on the centrality of French universities (when compared to the evolution of foreign ones) or a null one (when considering PROs as counterparts). The contrasting effect of the two sets of laws is also verified using the *betweenness index* as network centrality score of universities, in particular through the PSM estimation of the DID (see Appendix A).

6 Conclusions and Discussion

Innovation is the outcome of dynamic and collaborative networks among heterogeneous actors, whose diffusion goes along with the unique system characteristics (geographical, sectoral and institutional). Although previous studies focused on the interactions among innovative actors and the reasons for promoting university-industry collaboration, they failed to elaborate on how these relations change by adopting *ad hoc* laws. Studies on their development trends and their network distribution in patenting remain scarce.

This paper adds to the stream its contribution suggesting that institutional changes may set the conditions and incentives to conduct R&D and patenting activities between public and private actors while pushing universities to be more involved. The present study endeavoured to close the existing research gap by employing an unprecedented observation method to examine collaborative patents and determine the most central actors after new policy interventions in France. We thus assessed the impact of legislative changes adopted in the last decades on the relative importance of French Universities in co-patent networks. Initially, French universities were weakly engaged in patenting, compared to their European counterparts or to Public Research Organizations, in which most of the research occurred. From the end of the 1990s, including French Universities in the national innovation system has become a governmental priority, which translated through new policy intervention: Innovation Act (1999) and two other laws on research (2006) and academic freedom of universities (2007). The introduction of these laws targeted universities' intellectual property rights, research commercialisation, profit-oriented innovation, and the university-industry partnership, universities' mission, thus strengthening the incentives of universities and faculty to produce patents. Before the Innovation Act (1999), French universities lacked the incentives to commercialize research.

To assess the depth of the commitment of French universities in co-patenting strategies, we initially employed Network analysis to examine their centrality in patents collaboration networks among over 800 patents applicants. Then, to estimate the causal relationship between the change in the institutional background and the position of universities in patenting, we run several DIDs. We complemented our initial estimation strategy by incorporating a Kernel Propensity Score Matching (PSM). We contrasted the evolution of the centrality of French universities, (*our treatment group*), with two control groups: first with Italy and Germany, and with French PROs, as a robustness check.

Overall, we find that French universities have gained more importance and centrality in the French *patenting co-ownership* network over the years and became an essential actor in the French innovation system, despite a lower trend than in foreign countries. Shortly, the adoption of the Innovation Act (1999) fostered collaboration with French universities, making them more central and weighty actors in the French co-patents network. We believe that the centrality initially gained by French universities might be the outcome and the response to the new incentives induced by the Innovation Act (1999) to facilitate knowledge transfer and commercialize research. Besides granting property rights to university innovations publicly-funded, universities started seeking private funding to patent their research results. As pointed out in Bruno and Orsenigo (2003), the high degree of university specialization in specific fields attracts research funding rather than the ability of universities to produce patents. Conversely, 2007-on laws have a much more mitigated result, as we find it to be either negative or null, offsetting the initial trend. We believe that this outcome might also be a consequence of creating the Unité Mixte de Recherche (UMR) in France: an administrative entity created by signing an association contract between one (or more) research laboratories or PROs, like the National Center for Scientific Research (CNRS), with a higher education establishment, (e.g. university). Nowadays, UMR represents more than 50% of the research carried out by teams within a university. Yet, patent data present their limitations in not making clear this distinction, and it remains a simple assumption.

In general, the ownership distribution of IPRs have consequences for universities. We believe that university patenting might compromise open science and result in licensing for-profit, thus undermining the purity of the scientific endeavour. The search for knowledge and competencies outside the boundaries of firms, research centres and universities follow highly complex and evolving patterns hard to anticipate by policy-makers.

All this considered, our study is not exempt from limitations, and some interesting areas leave room for future research.

First, it is critical to empirically assess the interaction of legislative and organizational changes with the peculiarities of the local context. Further research should investigate the heterogeneity of such dynamics across fields at the country level (regional or metropolitan). Additional analyses could offer comprehensive insights on those sectors where the universities are central actors. Further quantifiable information on technological importance, IP exploitation and patent value would be needed to ascertain the impact of change in the IP regime in the countries considered. Qualitative information from interviews with university inventors and TTOs or case studies of university patent management before and after changes to the IP regime in different countries might be complementary.

Secondly, we limited our observations to patents filled in EPO PATSTAT even though we know that patents have a territorial dimension, and their application is closely associated with local market factors. Only investigating the technologies of EPO patents may cause results to be "biased" towards specific market preferences or trends. Therefore, including data from the national patent offices and verifying different data sources through triangulation and incorporating other forms of output (consulting, contract research) could expand the observation accuracy of domestic development. Yet, future research should keep in mind that national patents are recognised as an imperfect measure in cross-country comparisons (Grupp and Schmoch, 1999).

Last, other studies may adopt a behavioural approach to evaluate underlying trends in patenting activity, e.g., whether professional and personal motivations have changed after new legislation and contributed to the centrality of some universities.

All these limitations notwithstanding, we believe that our research brings an additional contribution to the existing literature. Besides providing a detailed description of how the interactions of French Universities and other innovative actors evolved in patenting activities, our study links the emergence of a new role for universities to institutional changes. This novel insight enriches us with a broader understanding of how dynamics evolved between firms, PROs, individuals and universities in France.

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References

Abadie, A. (2005). Semiparametric difference-in-differences estimators. *The Review of Economic Studies 72*(1), 1–19.

Abadie, A. and G. W. Imbens (2016). Matching on the estimated propensity score. *Econometrica 84*(2), 781–807.

Aghion, P., M. Dewatripont, C. Hoxby, A. Mas-Colell, and A. Sapir (2010). The governance and performance of universities: evidence from europe and the us. *Economic policy 25*(61), 7–59.

Aharonson, B. S., J. A. Baum, and M. P. Feldman (2014). Industrial clustering and innovative output. In *Innovation and IT in an International Context*, pp. 65–81. Springer.

Arora, A., S. Belenzon, and H. Lee (2018). Reversed citations and the localization of knowledge spillovers. *Journal of Economic Geography 18*(3), 495–521.

Arora, A., S. Belenzon, and A. Patacconi (2015). Killing the golden goose? the decline of science in corporate r&d. Technical report, National Bureau of Economic Research.

Arora, A., S. Belenzon, and A. Patacconi (2018). The decline of science in corporate r&d. *Strategic Management Journal 39*(1), 3–32.

Arora, A., S. Belenzon, and L. Sheer (2021). Knowledge spillovers and corporate investment in scientific research. *American Economic Review 111*(3), 871–98.

Arora, A. and A. Gambardella (1994). The changing technology of technological change: general and abstract knowledge and the division of innovative labour. *Research policy 23*(5), 523–532.

Arrow, K. J. (1962). Economic welfare and the allocation of resources for invention.

Bakker, J., D. Verhoeven, L. Zhang, and B. Van Looy (2016). Patent citation indicators: One size fits all? *Scientometrics 106*(1), 187–211.

Balconi, M., S. Breschi, and F. Lissoni (2004). Networks of inventors and the role of academia: an exploration of italian patent data. *Research policy 33*(1), 127–145.

Baldini, N., R. Fini, R. Grimaldi, and M. Sobrero (2010). The institutionalisation of university patenting activity in italy: Diffusion and evolution of organisational practices. Technical report, Working Paper (June 29, 2010).

Baldini, N., R. Grimaldi, and M. Sobrero (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.

Barthelemy, M., B. Gondran, and E. Guichard (2003). Spatial structure of the internet traffic. *Physica A: statistical mechanics and its applications 319*, 633–642.

Belenzon, S. and M. Schankerman (2013). Spreading the word: Geography, policy, and knowledge spillovers. *Review of Economics and Statistics 95*(3), 884–903.

Bianchini, S. and P. Llerena (2016). Science policy as a prerequisite of industrial policy. *Economia e Politica Industriale 43*(3), 273–280.

Bianchini, S., P. Llerena, and S. Patsali (2019). Demand-pull innovation in science: Empirical evidence from a research university's suppliers. *Research Policy: X 1*, 100005.

Bianchini, S., G. Pellegrino, and F. Tamagni (2018). Innovation complementarities and firm growth. *Industrial and Corporate Change 27*(4), 657–676.

Bikard, M. (2018). Made in academia: The effect of institutional origin on inventors' attention to science. *Organization Science 29*(5), 818–836.

Bikard, M. and M. Marx (2020). Bridging academia and industry: How geographic hubs connect university science and corporate technology. *Management Science 66*(8), 3425–3443.

Bonaccorsi, A. and G. Thoma (2005). Scientific and technological regimes in nanotechnology: combinatorial inventors and performance. Technical report, LEM working paper series.

Bonacich, P. (1972). Factoring and weighting approaches to status scores and clique identification. *The Journal of Mathematical Sociology 2*(1), 113–120.

Bonacich, P. (1987). Power and centrality: A family of measures. *American journal of sociology 92*(5), 1170–1182.

Borgatti, S. and M. Everett (2006, 10). A graph-theoretic perspective on centrality. *Social Networks 28*, 466–484.

Borgatti, S. P. and M. G. Everett (1997). Network analysis of 2-mode data. *Social networks 19*(3), 243–269.

Borgatti, S. P., M. G. Everett, and J. C. Johnson (2018). *Analyzing social networks.* Sage.

Breschi, S. and C. Catalini (2010). Tracing the links between science and technology: An exploratory analysis of scientists' and inventors' networks. *Research Policy 39*(1), 14–26.

Breschi, S., C. Lenzi, F. Lissoni, A. Vezzulli, et al. (2010). The geography of knowledge spillovers: the role of inventors' mobility across firms and in space. *The handbook of evolutionary economic geography, Cheltenham: Edward Elgar*, 353–369.

Breschi, S. and F. Lissoni (2001). Knowledge spillovers and local innovation systems: a critical survey. *Industrial and corporate change 10*(4), 975–1005.

Breschi, S. and F. Lissoni (2004). Knowledge networks from patent data. In *Handbook of quantitative science and technology research*, pp. 613–643. Springer.

Breschi, S. and F. Lissoni (2005). " cross-firm" inventors and social networks: Localized knowledge spillovers revisited. *Annales d'Economie et de Statistique*, 189–209.

Breschi, S., F. Lissoni, and F. Montobbio (2008). University patenting and scientific productivity: a quantitative study of italian academic inventors. *European Management Review 5*(2), 91–109.

Breschi, S., F. Malerba, and L. Orsenigo (2000). Technological regimes and schumpeterian patterns of innovation. *The economic journal 110*(463), 388–410.

Bruno, G. S. and L. Orsenigo (2003). Variables influencing industrial funding of academic research in italy: an empirical analysis. *International Journal of Technology Management 26*(2-4), 277–302.

Brusoni, S., O. Marsili, and A. Salter (2005). The role of codified sources of knowledge in innovation: Empirical evidence from dutch manufacturing. *Journal of Evolutionary Economics 15*(2), 211–231.

Carayol, N. and E. Carpentier (2021). The spread of academic invention: A nationwide case study on french data (1995-2012). Technical report.

Carayol, N., E. Carpentier, et al. (2019). Public policy and the evolution of technology transfer in france. Technical report.

Cassi, L., N. Corrocher, F. Malerba, and N. Vonortas (2008). The impact of eu-funded research networks on knowledge diffusion at the regional level. *Research Evaluation 17*(4), 283–293.

Cassi, L. and A. Plunket (2015). Research collaboration in co-inventor networks: combining closure, bridging and proximities. *Regional Studies 49*(6), 936–954.

Chai, S. and W. Shih (2016). Bridging science and technology through academic–industry partnerships. *Research Policy 45*(1), 148–158.

Chang, S.-H. (2017). The technology networks and development trends of university-industry collaborative patents. *Technological Forecasting and Social Change 118*, 107–113.

Clayton, P., M. Feldman, and N. Lowe (2018). Behind the scenes: Intermediary organizations that facilitate science commercialization through entrepreneurship. *Academy of Management Perspectives 32*(1), 104–124.

Cohen, W. M. and D. A. Levinthal (1989). Innovation and learning: the two faces of r & d. *The economic journal 99*(397), 569–596.

Cohen, W. M. and D. A. Levinthal (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative science quarterly*, 128–152.

Crescenzi, R. (2021). R&d, innovative collaborations and the role of public policies. In *The Economics of Big Science*, pp. 99–103. Springer, Cham.

Crescenzi, R., M. Nathan, and A. Rodríguez-Pose (2016). Do inventors talk to strangers? on proximity and collaborative knowledge creation. *Research Policy 45*(1), 177–194.

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

Czarnitzki, D., T. Doherr, K. Hussinger, P. Schliessler, and A. A. Toole (2015). Individual versus institutional ownership of university-discovered inventions. *ZEW-Centre for European Economic Research Discussion Paper* (15-007).

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

David, P. A. and D. Foray (1995). Accessing and expanding the science and technology knowledge base. Technical report.

De Rassenfosse, G., H. Dernis, and G. Boedt (2014). An introduction to the patstat database with example queries. *Australian economic review 47*(3), 395–408.

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

Dibiaggio, L. and L. Nesta (2005). Patents statistics, knowledge specialisation and the organisation of competencies. *Revue d'économie industrielle 110*(1), 103–126.

Donegan, M. and M. Feldman (2019). Institutional evolution and the collaborative development of technology transfer capabilities. *International Regional Science Review*, 0160017620922886.

Dosi, G. (1983). Technological paradigms and technological trajectories. *Research Policy 11*(3).

Dosi, G. (1988). Sources, procedures, and microeconomic effects of innovation. *Journal of economic literature*, 1120–1171.

Dosi, G., P. Llerena, and M. S. Labini (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.

Dosi, G. and R. R. Nelson (2010). Technical change and industrial dynamics as evolutionary processes. *Handbook of the Economics of Innovation 1*, 51–127.

Duflo, E., R. Glennerster, and M. Kremer (2007). Using randomization in development economics research: A toolkit. *Handbook of development economics 4*, 3895–3962.

Eslami, M. H., N. Lakemond, and S. Brusoni (2018). The dynamics of knowledge integration in collaborative product development: Evidence from the capital goods industry. *Industrial Marketing Management 75*, 146–159.

Etzkowitz, H. (2003). Innovation in innovation: The triple helix of university-industry-government relations. *Social science information 42*(3), 293–337.

Etzkowitz, H. and L. Leydesdorff (1995). The triple helix–university-industry-government relations: A laboratory for knowledge based economic development. *EASST review 14*(1), 14–19.

Feldman, M. P., M. Halbinger, T. Reichstein, F. Valentin, and J. W. Yoon (2019). Technological achievements in entrepreneurial firms–legacy, value chain experience, and division of innovation labour. *Industry and Innovation 26*(3), 243–268.

Fontana, R., A. Geuna, and M. Matt (2006). Factors affecting university–industry r&d projects: The importance of searching, screening and signalling. *Research policy 35*(2), 309–323.

Fontana, R., A. Nuvolari, H. Shimizu, and A. Vezzulli (2013). Reassessing patent propensity: Evidence from a dataset of r&d awards, 1977–2004. *Research Policy 42*(10), 1780–1792.

Fredriksson, A. and G. M. de Oliveira (2019). Impact evaluation using difference-in-differences. *RAUSP Management Journal.*

Freeman, C. (1995). The 'national system of innovation'in historical perspective. *Cambridge Journal of economics 19*(1), 5–24.

Freeman, L. C. (1978). Centrality in social networks conceptual clarification. *Social networks 1*(3), 215–239.

Geuna, A. and L. J. Nesta (2006). University patenting and its effects on academic research: The emerging european evidence. *Research policy 35*(6), 790–807.

Gittelman, M. (2007). Does geography matter for science-based firms? epistemic communities and the geography of research and patenting in biotechnology. *Organization Science 18*(4), 724–741.

Gómez, J., I. Salazar, and P. Vargas (2020). The role of extramural r&d and scientific knowledge in creating high novelty innovations: an examination of manufacturing and service firms in spain. *Research Policy 49*(8), 104030.

Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of Econometrics.*

Grossman, G. M. and E. Helpman (2002). Integration versus outsourcing in industry equilibrium. *The Quarterly Journal of Economics 117*(1), 85–120.

Grossman, S. J. and O. D. Hart (1986). The costs and benefits of ownership: A theory of vertical and lateral integration. *The Journal of Political Economy*, 691–719.

Grupp, H. and U. Schmoch (1999). Patent statistics in the age of globalisation: new legal procedures, new analytical methods, new economic interpretation. *Research Policy 28*(4), 377–396.

Heckman, J. J., H. Ichimura, and P. Todd (1998). Matching as an econometric evaluation estimator. *The review of economic studies 65*(2), 261–294.

Huggins, R., D. Prokop, and P. Thompson (2020). Universities and open innovation: The determinants of network centrality. *The Journal of Technology Transfer 45*(3), 718–757.

Hvide, H. K. and B. F. Jones (2018). University innovation and the professor's privilege. *American Economic Review 108*(7), 1860–98.

Jaffe, A. B. (1989). Real effects of academic research. *The American economic review*, 957–970.

Jaffe, A. B., M. Trajtenberg, and R. Henderson (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *the Quarterly journal of Economics 108*(3), 577–598.

Jonkers, K. and F. Sachwald (2018). The dual impact of 'excellent'research on science and innovation: the case of europe. *Science and Public Policy 45*(2), 159–174.

Joyez, C. (2017). On the topological structure of multinationals network. *Physica A: Statistical Mechanics and its Applications 473*, 578 – 588.

Joyez, C. (2020, April). NW_PROJECTION: Stata module to project a bipartite network into one of its two dimensions. Statistical Software Components, Boston College Department of Economics.

Kongsted, H., V. Tartari, D. Cannito, M. T. Norn, and J. Wohlert (2017). University researchers' engagement with industry, the public sector and society: Results from a 2017 survey of university researchers in denmark.

Lamperti, F., F. Malerba, R. Mavilia, and G. Tripodi (2020). Does the position in the intersectoral knowledge space affect the international competitiveness of industries? *Economics of Innovation and New Technology 29*(5), 441–488.

Laursen, K. and A. Salter (2006). Open for innovation: the role of openness in explaining innovation performance among uk manufacturing firms. *Strategic management journal 27*(2), 131–150.

Lechner, M. et al. (2011). *The estimation of causal effects by difference-in-difference methods.* Now.

Leiponen, A. and C. E. Helfat (2010). Innovation objectives, knowledge sources, and the benefits of breadth. *Strategic management journal 31*(2), 224–236.

Leoncini, R., M. A. Maggioni, and S. Montresor (1996). Intersectoral innovation flows and national technological systems: network analysis for comparing italy and germany. *Research Policy 25*(3), 415–430.

Lindelöf, P. and H. Löfsten (2004). Proximity as a resource base for competitive advantage: University–industry links for technology transfer. *The Journal of Technology Transfer 29*(3), 311–326.

Lissoni, F. (2012). Academic patenting in europe: An overview of recent research and new perspectives. *World patent information 34*(3), 197–205.

Lissoni, F., P. Llerena, and B. Sanditov (2013). Small worlds in networks of inventors and the role of academics: An analysis of france. *Industry and Innovation 20*(3), 195–220.

Lissoni, F., P. Llerena, B. Sanditov, et al. (2011). Small worlds in networks of inventors and the role of science: An analysis of france. *Bureau d'Economie Théorique et Appliquée, UDS, Strasbourg.*

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

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

Malerba, F. (1992). Learning by firms and incremental technical change. *The economic journal 102*(413), 845–859.

Malerba, F. (2004). *Sectoral systems of innovation: concepts, issues and analyses of six major sectors in Europe*. Cambridge University Press.

Malerba, F. and K. Lee (2020). An evolutionary perspective on economic catch-up by latecomers. *Industrial and Corporate Change*.

Malerba, F., M. L. Mancusi, and F. Montobbio (2013). Innovation, international r&d spillovers and the sectoral heterogeneity of knowledge flows. *Review of World Economics 149*(4), 697–722.

Malerba, F. and M. McKelvey (2020). Knowledge-intensive innovative entrepreneurship integrating schumpeter, evolutionary economics, and innovation systems. *Small Business Economics 54*(2), 503–522.

Malerba, F. and G. P. Pisano (2019). Innovation, competition and sectoral evolution: an introduction to the special section on industrial dynamics. *Industrial and Corporate Change 28*(3), 503–510.

Marengo, L., C. Pasquali, M. Valente, and G. Dosi (2012). Appropriability, patents, and rates of innovation in complex products industries. *Economics of Innovation and New Technology 21*(8), 753–773.

Martinez, C. and L. Bares (2018). The link between technology transfer and international extension of university patents: Evidence from spain. *Science and Public Policy 45*(6), 827–842.

Martínez, C. and V. Sterzi (2021). The impact of the abolishment of the professor's privilege on european university-owned patents. *Industry and Innovation 28*(3), 247–282.

Marzucchi, A., D. Antonioli, and S. Montresor (2015). Industry–research co-operation within and across regional boundaries. what does innovation policy add? *Papers in Regional Science 94*(3), 499–524.

Mina, A. (2009). The emergence of new knowledge, market evolution and the dynamics of micro-innovation systems. *Economics of Innovation and New Technology 18*(5), 447–466.

Mina, A., D. Connell, A. Hughes, et al. (2009). *Models of technology development in intermediate research organisations*. Citeseer.

Nelson, R. R. (1959). The simple economics of basic scientific research. *Journal of political economy 67*(3), 297–306.

Nelson, R. R. (1991). Why do firms differ, and how does it matter? *Strategic management journal 12*(S2), 61–74.

Nesta, L. and L. Dibiaggio (2003). Technology strategy and knowledge dynamics: The case of biotech[1]. *Industry and Innovation 10*(3), 331–349.

Nesta, L., V. Mangematin, et al. (2004a). The dynamics of innovation networks. *Science Technology Policy Research 4*, 17–28.

Nesta, L., V. Mangematin, et al. (2004b). The dynamics of innovation networks. *Science Technology Policy Research 4*, 17–28.

Nesta, L. and P. P. Saviotti (2005). Coherence of the knowledge base and the firm's innovative performance: Evidence from the us pharmaceutical industry. *The Journal of Industrial Economics 53*(1), 123–142.

Newman, M. E. (2004). Coauthorship networks and patterns of scientific collaboration. *Proceedings of the national academy of sciences 101*(suppl 1), 5200–5205.

Nishimura, J. and H. Okamuro (2011). R&d productivity and the organization of cluster policy: An empirical evaluation of the industrial cluster project in japan. *The Journal of Technology Transfer 36*(2), 117–144.

Opsahl, T., F. Agneessens, and J. Skvoretz (2010). Node centrality in weighted networks: Generalizing degree and shortest paths. *Social Networks 32*(3), 245–251.

Pasimeni, F. (2019). Sql query to increase data accuracy and completeness in patstat. *World Patent Information 57*, 1–7.

Patel, P. and K. Pavitt (1997). The technological competencies of the world's largest firms: complex and path-dependent, but not much variety. *Research policy 26*(2), 141–156.

Perkmann, M., R. Fini, J.-M. Ross, A. Salter, C. Silvestri, and V. Tartari (2015). Accounting for universities' impact: Using augmented data to measure academic engagement and commercialization by academic scientists. *Research Evaluation 24*(4), 380–391.

Perkmann, M., V. Tartari, M. McKelvey, E. Autio, A. Broström, P. D'este, R. Fini, A. Geuna, R. Grimaldi, A. Hughes, et al. (2013). Academic engagement and commercialisation: A review of the literature on university–industry relations. *Research policy 42*(2), 423–442.

Perkmann, M. and K. Walsh (2007). University–industry relationships and open innovation: Towards a research agenda. *International journal of management reviews 9*(4), 259–280.

Powell, W. W., K. W. Koput, and L. Smith-Doerr (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative science quarterly*, 116–145.

Quatraro, F. and A. Scandura (2020). Regional patterns of unrelated technological diversification: the role of academic inventors.

Raghupathi, V. and W. Raghupathi (2019). Exploring science-and-technology-led innovation: a cross-country study. *Journal of Innovation and Entrepreneurship 8*(1), 1–45.

Rosenbaum, P. R. and D. B. Rubin (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika 70*(1), 41–55.

Singh, J. (2005). Collaborative networks as determinants of knowledge diffusion patterns. *Management science 51*(5), 756–770.

Singh, J. and M. Marx (2013). Geographic constraints on knowledge spillovers: Political borders vs. spatial proximity. *Management Science 59*(9), 2056–2078.

Smith, H. L. (2006). *Universities, innovation and the economy*. Routledge New York.

Stephan, A., C. R. Bening, T. S. Schmidt, M. Schwarz, and V. H. Hoffmann (2019). The role of inter-sectoral knowledge spillovers in technological innovations: The case of lithium-ion batteries. *Technological Forecasting and Social Change 148*, 119718.

Sterzi, V., M. Pezzoni, and F. Lissoni (2019). Patent management by universities: evidence from italian academic inventions. *Industrial and Corporate Change 28*(2), 309–330.

Stuart, E. A., H. A. Huskamp, K. Duckworth, J. Simmons, Z. Song, M. E. Chernew, and C. L. Barry (2014). Using propensity scores in difference-in-differences models to estimate the effects of a policy change. *Health Services and Outcomes Research Methodology 14*(4), 166–182.

Tarkowski, M. K., T. P. Michalak, T. Rahwan, and M. Wooldridge (2017). Game-theoretic network centrality: A review. *arXiv preprint arXiv:1801.00218*.

Tartari, V. and S. Breschi (2012). Set them free: scientists' evaluations of the benefits and costs of university–industry research collaboration. *Industrial and Corporate Change 21*(5), 1117–1147.

Tartari, V. and S. Stern (2018). The role of universities in local entrepreneurial ecosystems.

Tetsuo, W. et al. (2018). The choice of examiner patent citations for refusals: Evidence from the trilateral offices. Technical report.

Von Proff, S., G. Buenstorf, and M. Hummel (2012). University patenting in germany before and after 2002: what role did the professors' privilege play? *Industry and Innovation 19*(1), 23–44.

Walsh, J. P. and H. Huang (2014). Local context, academic entrepreneurship and open science: Publication secrecy and commercial activity among japanese and us scientists. *Research Policy 43*(2), 245–260.

Walsh, J. P., Y.-N. Lee, and S. Nagaoka (2016). Openness and innovation in the us: Collaboration form, idea generation and implementation. *Research Policy 45*(8), 1660–1671.

Watts, D. J. and S. H. Strogatz (1998). Collective dynamics of 'small-world'networks. *nature 393*(6684), 440–442.

Wooldridge, J. M. (2015). *Introductory econometrics: A modern approach*. Cengage learning.

A Results using betweeness centrality

A.1 Descriptive Statistics

Table 9: Network Index

Network index	1978 - 1999	2000-2007	2008-2018
Average betweeness centrality	0.278	0.256	0.174
univ	0.076	0.103	0.156
companies	0.205	0.168	0.098
PROs	0.955	1.271	0.599
Top ranked university	Univ. Sciences et Techn. de Lille	Univ. de Poitier	Univ. Claude Bernard Lyon 1
rank	31	19	8
Nb of universities in top 50	3	12	15

A.2 Differences in Differences

Table 10: Differences in Differences model. Control group : Abroad Universities

	(1) Betweeness Centrality (log) 1983-1999	(2) Betweeness Centrality (log) 1999-2018
FrenchUniv.	1.490*	0.475
	(1.67)	(1.44)
LegChange1	0.779	
	(1.18)	
FrenchUniv.*LegChange1	-0.733	
	(-1.04)	
LegChange2		-0.377
		(-1.47)
FrenchUniv.*LegChange2		-1.16***
		(-4.08)
pat_number (log)	1.427***	1.070***
	(4.00)	(7.51)
pat_famsize (log)	-0.176	-0.266
	(-0.29)	(-0.685)
pat_citations (log)	-0.004	-0.268*
	(0.02)	(-1.85)
pat_divtechn (log)	-0.007	0.479
	(-0.014)	(1.65)
pat_shgranted (log)	0.586	0.646
	(0.57)	(1.12)
_cons	-3.609**	-2.045**
	(-1.89)	(-2.43)
N	192	383
adj. R^2	0.827	0.800
NUTS3 Fixed Effects	Yes	Yes

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 11: Differences in Differences model. Control group : French PROs

	(1) Betweeness Centrality (log) 1983-1999	(2) Betweeness Centrality (log) 1999-2018
FrenchUniv.	0.378	0.274
	(1.06)	(1.00)
LegChange1	0.215	
	(0.76)	
FrenchUniv.*LegChange1	-0.032	
	(-0.07)	
LegChange2		-0.737***
		(-3.05)
FrenchUniv.*LegChange2		-0.411
		(-1.42)
pat_number (log)	1.277***	1.052***
	(9.74)	(13.08)
pat_famsize (log)	-0.501	-0.479**
	(-.143)	(-1.97)
pat_citations (log)	0.256	0.028
	(1.45)	(0.22)
pat_divtechn (log)	-0.190	0.271
	(-0.64)	(1.45)
pat_shgranted (log)	0.226	0.706*
	(0.47)	(1.94)
_cons	-0.833	-1.058*
	(-0.89)	(-1.93)
N	177	277
adj. R^2	0.771	0.780
NUTS3 Fixed Effects	Yes	Yes

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A.3 Propensity Score Matching DID

Table 12: Propensity Score Matching DID. Control group : Foreign Universities

	(1) Betweeness Centrality (log) 1983-1999	(2) Betweeness Centrality (log) 1999-2018
FrenchUniv.	-0.553	-0.207
	(1.01)	(0.68)
LegChange1	1.482**	
	(2.66)	
FrenchUniv.*LegChange1	-0.350	
	(0.43)	
LegChange2		1.847***
		(5.97)
FrenchUniv.*LegChange2		-1.060**
		(2.44)
_cons	1.505***	1.590 ***
	(3.89)	(7.41)
N	76	242
adj. R^2	0.17	0.18

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 13: Propensity Score Matching DID. Control group : French PROs

	(1) Betweeness Centrality (log) 1983-1999	(2) Betweeness Centrality (log) 1999-2018
FrenchUniv.	0.092	0.599*
	(0.28)	(1.95)
LegChange1	-0.512	
	(1.11)	
FrenchUniv.*LegChange1	1.609***	
	(2.77)	
LegChange2		0.354
		(1.11)
FrenchUniv.*LegChange2		0.456
		(1.03)
_cons	0.757***	0.764***
	(3.21)	(3.52)
N	102	164
adj. R^2	0.15	0.12

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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