University technology transfer and the evolution of regional specialization: the case of Turin

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Abstract

The paper is aimed at obtaining a better understanding of the role played by universities in the technological development and specialization of the territories in which they are located. Our methodology adopts both quantitative and qualitative techniques. First, we provide evidence of the interplay between the technological specialization of universities and the evolution of the technological trajectories of firms located in Italian NUTS3 regions. We also propose an original taxonomy of university-region technological evolution processes that leads to the identification of four possible models and reveals substantial heterogeneity in university-region specialization processes.
Finally, we analyze the underlying mechanisms of university technology transfer activities in more detail, by using the Politecnico di Torino as a single case study. The case examines how the university has changed its strategy by modifying the mix of exploitation and exploration strategies to continue increasing the technological proximity with the local ecosystem under conditions of rapid and radical change. Our work offers important implications for both regional technology policies and the management of universities.

Keywords: knowledge spillover, regional branching, university patenting, technological specialization, RTA
JEL: O32, O33, O34

1. Introduction

In recent years, increasing attention has been devoted, by both academics and policy makers, to the processes through which regions develop and specialize over time. According to the recent evolutionary approach to economic geography, regions evolve by following a regional branching process, through which new industries and technologies are generated from industries and technologies that are related to pre-existing ones (Frenken and Boschma, 2007; Boschma and Frenken, 2011). In this vein, regional specialization is a path-dependent process that depends on the accumulated and related technological competencies that are likely to shape the emergence of new industries and technologies at the local level. Several studies have confirmed such a thesis in different geographical contexts (e.g., Neffke et al., 2011; Boschma et al., 2013; Colombelli et al., 2014). These results have contributed to making regional branching the scientific background of the latest wave of regional policies, based on the concept of Smart Specialization Strategies (Boschma, 2014). Such policies are aimed at identifying strategic areas of intervention to make innovation flourish in a region by building on cumulated knowledge, collective intelligence, and distinctive assets of the territory (Foray, 2014).

Within the regional branching literature, attention has mainly been devoted to the role of firms in engendering structural change of regions and specialization in such cross-cutting technologies as KETs (Montresor and Quatraro, 2017; Neffke et al., 2018; Evangelista et al., 2018). On a parallel ground, the regional economics literature has analysed the impact of universities as actors in economic and industrial development by focusing on the contribution of universities to local economic growth (Jaffe et al., 1993; Feldman, 1994; Etzkowitz and Leydesdorff, 1995; Keeble, 2001; Druilhe and Garnsey, 2004), productivity (Griliches, 1979; Jaffe, 1989), urban development (Lazzeroni and Piccaluga, 2015), and, more recently, to the ability of universities to promote socially-desirable outcomes through increasing civic engagement (Gunasekara, 2006; Uyarra, 2010; Etzkowitz, 2001; Breznitz and Feldman, 2012b,a). However, limited attention has been devoted to the role of academic institutions in shaping regional branching processes and, in particular, to the differential role that knowledge and technologies generated from universities can exert, depending on local contingent factors.

This gap is surprising as universities can play a fundamental role in regional specialization processes because they are key sources of new knowledge, which can be transferred to the local ecosystem through a variety of channels (d'Este and Patel, 2007). First, universities feed the local ecosystem with highly educated and skilled individuals, contribute to skill upgrading through life-long learning programs and attract talent to the local ecosystem (Bramwell and Wolfe, 2008; d'Este and Patel, 2007). Universities also interact with local industrial partners in order to transfer the results of their internal R&D through formal mechanisms such as patenting, licensing, and research collaboration, in addition to informal mechanisms such as consulting, networking, and face-to-face communication (Bonaccorsi and Piccaluga, 1994; Cohen et al., 2002; Friedman and Silberman, 2003; Link et al., 2007; d'Este and Patel, 2007; Perkmann and Walsh, 2007). Moreover, universities promote the diffusion of an entrepreneurial culture among students and academics and stimulate the creation of new firms within the ecosystem (Carree et al., 2014; Shane, 2004; Zucker et al., 1998; Bonaccorsi et al., 2013). Despite this evidence, the contribution of academic knowledge to the evolution of regional specialization has almost been neglected.

To fill this gap, this paper provides an original taxonomy and a new methodology for the analysis of university-region technological evolution processes. Our taxonomy is based on two dimensions (convergent versus divergent and region-pull versus university-push processes) and leads to the identification of four possible models of university-region technological evolution processes. In our framework, the impact of universities on the local technological development and specialization depends upon three contingent factors: the specificities of local universities (university exploitation versus exploration strategies), the degree of innovation capabilities and absorptive capacity of local firms (high versus low absorptive capacity), and the strength of the links between local firms and universities (tight versus loose innovation ecosystems).

Our framework allows the following research questions to be answered. Do the technological trajectories of regions and universities co-evolve? Is it possible to identify different models of technological co-evolution? Who leads the local technological evolution processes: the university or the region? What is the role of contingent factors at the university, firm, and system-level?

In the empirical section of this paper, we exploit a novel dataset collecting all patent applications filed at the Italian Patent and Trademark Office (UIBM) by national universities and firms. Subsequently, we focus on the case of Politecnico di Torino. Italy represents an interesting laboratory to help understand university technology transfer activities. Italy is well known for its industrial districts in traditional industries (Becattini, 1990), as its industrial structure is mainly composed of SMEs, and also for its international competitiveness in several medium-tech industries. A variety of technological and industrial specializations that are linked to a wide range of idiosyncratic knowledge can be found in Italy. In this context, universities can act as knowledge intermediaries between local SMEs and large companies. Moreover, during the period under scrutiny, the country underwent major legislative changes that fostered the Italian academic patenting activity. Within such context, Turin represents an interesting case, because the city has historically evolved from a traditional industrial setting, with the Fiat carmaker at its center in a directive role, to a more sophisticated and technologically diversified system, which is today only partially linked to the local automotive production system (Whitford and Enrietti, 2005; Colombelli, 2006; Quatraro, 2007; Colantonio et al., 2013; Colombelli et al., 2019). The industrial setting, originally tailored to the demands of the automotive industry, has progressively been reshaped to include emerging businesses in new sectors. The local university system has played a crucial role in this profound economic and industrial transformation.

The contribution of the paper to the literature is twofold. From the theoretical point of view, we develop an original framework, which allows identifying a taxonomy composed of four models of university-region technological evolution. This is a relevant contribution, given that the previous literature, mainly pertaining to the Systems of Innovation (SI) and Triple Helix (TH) approaches, implicitly assumed the existence of a preferred model of knowledge diffusion where the firm (Freeman, 1987, 1995; Lundvall, 2010; Nelson, 1993; Nelson and Rosenberg, 1993; Breschi and Malerba, 1997; Edquist, 1997) or the university (Etzkowitz and Leydesdorff, 1995, 2000; Leydesdorff and Etzkowitz, 1996, 1998) was the core agent. The present framework also takes into account the role of local contingent factors in the dynamics of knowledge transfer within the ecosystem. Many factors, at different levels of analysis, may affect the effectiveness of knowledge transfer from universities to firms (Muscio and Vallanti, 2014; Bruneel et al., 2010). From a methodological point of view, the empirical approach allows our conceptual framework to be operationalized by bringing together indicators that can be used to measure the technology specialization of regions and universities as well as the technological distances between them. Such methodology could be used in future research for analysing with more precision the co-evolution between the technological trajectories of universities and the territories to which the academic institutions belong to. Finally, while previous literature mainly focused on successful high-tech local areas, our empirical analysis focuses on territories specialised in traditional industries and medium-tech technologies.

The remaining part of the paper is structured as follows. The theoretical framework underpinning the analysis and the original taxonomy of university-region technological evolution processes is provided in Section 2. The data and the used methodology are presented in Section 3. Section 4 presents the results of the descriptive analysis on the co-evolution of technological trajectories of Italian NUTS3 regions in Italy and the corresponding local universities. We analyse the underlying strategies behind the university-region technological co-evolution processes in more detail in Section 5 by using the perspective of the university, with reference to the case of the Politecnico di Torino. The concluding section summarizes the results of the analysis and explores the implications.

2. Theoretical background

2.1 Impact of universities on industrial innovation and specialization

The recent economic geography literature on regional branching and technological specialization shows that regions stay close to their existing capabilities when diversifying into new products and technologies (Boschma and Frenken, 2011). These dynamics are engendered by the cumulative nature of innovation processes, the existence of learning economies in knowledge generation, and the localized nature of knowledge spillovers (Jaffe et al., 1993; Jaffe and Trajtenberg, 1999; Antonelli, 1995). Such evidence has stimulated the debate, in both policy and academic circles, about the role of technological specialization on regional performance. By relying on the concept of Smart Specialization (Foray, 2009), the European Commission has encouraged territories to build their comparative advantages on their distinctive technological capabilities. However, the debate on regional diversification patterns has started questioning the desirability of such strategies, because of path-dependence and lock-in effects. More recently, the European Commission has introduced policies that promote the concepts of open innovation ecosystems (EC, 2017) and technological leadership (EC, 2018). A prominent example is the establishment of the European Innovation Council (EC, 2017; 2018) which should favour, among other goals, the technological transition toward digitalization and circular economy (EC, 2017).

The understanding of the factors that help regions to sustain their competitive advantage, through technological specialization dynamics, thus becomes of paramount importance. Universities may exert a crucial role in this process, as they are key sources of knowledge for the local ecosystem. However, to the best of our knowledge, no attempt has been made to disentangle the role of academic knowledge in regional branching processes.

The regional economics literature has instead provided a great deal of evidence on the impact of the research activities of universities on regional innovation performances. Within this domain, a number of empirical analyses have examined the spillover effects of academic research by adopting the knowledge production function approach (Griliches, 1979; Anselin et al., 1997; Jaffe, 1989; Acs et al., 1992; Anselin et al., 2000; Fritsch and Slavtchev, 2007; Leten et al., 2014). These quantitative analyses have provided evidence of a positive relationship between academic research and the innovative activities that occur within a geographical area and have confirmed the importance of proximity between firms and universities for the innovation process. Other works have studied the effects of academic research on regional innovation dynamics through qualitative analyses (Mansfield, 1991; Mansfield and Lee, 1996; Mansfield, 1998; Cohen et al., 2002; Arundel and Geuna, 2004; Laursen et al., 2011). These works revealed that universities positively contribute to the introduction of technological innovations in various industries and to the decrease in time lags between the investments in scientific research projects and the industrial utilization of their findings (Mansfield, 1991, 1998). Moreover, these empirical analyses have shown that firms are more willing to collaborate with universities on the basis of proximity and research quality (Mansfield and Lee, 1996; Arundel and Geuna, 2004; Laursen et al., 2011).

Both streams of literature have revealed that proximity matters. The geographical closeness between universities and firms is important because the exchanged knowledge is cumulative, localized, and tacit in nature (Antonelli, 1995) allowing local firms to access the results of academic research more easily (Mansfield and Lee, 1996; Arundel and Geuna, 2004). Geographical proximity may also strengthen other forms of proximity such as cognitive, organizational, and technological closeness, which are essential for both the learning process and the successful generation and exploitation of knowledge and capabilities (Boschma, 2005).

However, only a few empirical papers in the scientific literature have empirically tested the impact of academic research on the technological trajectories of geographical areas, and vice versa (Calderini and Scellato, 2005; Braunerhjelm, 2008; Acosta et al., 2009; Coronado et al., 2017). Overall, these contributions provide mixed results concerning the existence, the direction and the causal relationship between academic research and industrial specialization. We aim to contribute to this debate by analysing the co-evolution of technological trajectories of universities and geographical areas in Italy, taking into account the role of contingent factors at the university, firm, and ecosystem levels. The literature has indeed emphasized that many factors, at different levels of analysis, may affect the effectiveness of knowledge transfer from universities to firms (Muscio and Vallanti, 2014; Bruneel et al., 2010).

At the university level, the ability of academies to transfer technological knowledge and to exert an impact on the local ecosystem is related to the institutional and organizational resources of the university. Since the upsurge of the third mission, academic institutions have increasingly faced the tensions between academic excellence and research commercialization. Previous works showed that universities need to manage this tension by acting as ambidextrous organizations (Gibson and Birkinshaw, 2004; Raisch and Birkinshaw, 2008; Tushman and O'Reilly, 1996). This is possible through the creation of dual structures that provide universities with the simultaneous capability for two different but interrelated activities, that is achieving academic rigor and commercialization. These dual structures include academic departments – the traditional academic part of the organization in charge of scientific excellence – and TTOs – separate entities within the organization that focus on the commercialization of academic research by acting as brokers between academia and industry (Ambos et al., 2008; Chang et al., 2009). Ambidexterity allows universities to combine exploration and exploitation strategies. They can explore new avenues through basic research and academic excellence, while also exploiting the technological knowledge accumulated over time at the local level, through applied research that is more oriented toward the commercialization of scientific results. This exerts a positive impact on the generation of regional knowledge and innovation processes, which are affected positively by a mix of exploitation and exploration of the existing technological knowledge.

The effectiveness of academic knowledge transfer is also affected by firm-level factors. A key firm-level factor that can influence the effects of academic research on regional innovation dynamics is the absorptive capacity of local firms (Cohen and Levinthal, 1990; Fritsch and Kublina, 2018; Qian and Jung, 2017). The knowledge generation process requires a combination of diverse and complementary capabilities of heterogeneous economic actors (Nooteboom, 2000). However, given the tacit and idiosyncratic nature of knowledge, such recombination process is not easy. The effective transfer of knowledge from one organization to another requires the recipient organization to have a high absorptive capacity for being able to identify, interpret, and exploit new knowledge (Boschma, 2005). In this vein, Laursen et al. (2011) showed that geographical proximity increases the probability of collaboration between university and firms.

Interestingly, they also found such a result is stronger for firms with a lower absorptive capacity. Unlike firms with high levels of absorptive capacity, such firms may not have the capacity or the resources to collaborate with geographically distant universities. Firms with low levels of absorptive capacity are thus more inclined to choose local university partners. However, the capacity of actors to absorb new knowledge also requires cognitive proximity. Organizations that share the same knowledge base are more likely to learn from each other. The effective transfer of knowledge from a university to local firms is thus affected by the degree of university-firm technological proximity (Boschma, 2005).

Finally, the effects of academic research on regional innovation dynamics are also influenced by the presence of a socio-economic context that enables university-industry links (Braunerhjelm, 2008). Knowledge generation depends upon the capability of effectively coordinating the knowledge recombination process and the exchange of complementary knowledge among organizations within the local system. The transfer of complex knowledge thus requires close relationships between agents (Hansen, 1999; Cooke et al., 1999).

In view of the aforementioned arguments, our framework for the analysis of university-region technological evolution processes also takes into account the role of contingent factors at the university, firm, and ecosystem levels.

2.2 Conceptual framework

In order to analyse how university-region technological evolution processes are affected by factors at the university, firm and ecosystem levels, we provide an original taxonomy, which is based on two dimensions: i) the direction of the technological evolution process that allows divergent processes to be distinguished from convergent ones, and ii) the leading role of local universities versus firms in the entry of a new technology that allows region-pull versus university-push processes to be identified (Figure 1). We offer a more detailed description of these two dimensions that are then operationalized using patent data filed by universities and firms located in a specific territory.

In divergent processes, the technological specialization of universities and local firms follows different trajectories (Acosta et al., 2009), while convergent ones are characterized by increasing technological proximity over time between local firms and universities (Calderini and Scellato, 2005; Braunerhjelm, 2008). In the case of region-pull processes, local firms exert the leading role and guide the evolution of the local technological specialization (Coronado et al., 2017), while in university-push processes, regional technological trajectories are driven by local universities through their entry into new technological fields (Calderini and Scellato, 2005; Braunerhjelm, 2008).

This taxonomy leads to the identification of four possible models of university-region technological evolution processes (Figure 1). In line with previous literature, we claim that each of these models is influenced by the specificities of the local universities (university exploitation versus exploration strategies), the degree of innovation capabilities, and absorptive capacity of the local firms (high versus low absorptive capacity), and the strength of the links between the local firms and universities (tight versus loose innovation ecosystems).

Quadrant A (Figure 1) refers to convergent-region-pull processes: the technological proximity between firms and universities increases over time as the result of a tight local innovation system sustained by strong university-industry links (Hansen, 1999; Cooke and Morgan, 1999; Braunerhjelm, 2008). The process is mostly pulled by local firms that have high innovation capabilities and is supported by research activities conducted by local universities that leverage on the local knowledge and technological specializations. In this configuration, universities adopt exploitation strategies that are aimed at leveraging on knowledge accumulated over time at the local level through applied research projects developed in collaboration with local firms (Ambos et al., 2008; Chang et al., 2009). Quadrant B refers to convergent-university-push processes that are also characterized by tight local innovation ecosystems. However, in this case, the leading role in the technological specialization process is played by local universities, which follow an exploration approach, and thus contribute to the development of new knowledge and competencies in the local ecosystem (Ambos et al., 2008; Chang et al., 2009). However, the convergent process is made possible by the contingent high absorptive capacity of local firms. Quadrant D refers to the case in which the presence of universities entering into new technological fields is not enough to support a convergent process. If such universities are located in a loose innovation ecosystem, composed of firms with a low absorptive capacity, the evolution process may not lead to a convergent technological specialization process. Finally, quadrant C refers to region-pull divergent processes that are more likely to occur in areas where local firms are characterized by high innovation capabilities and local universities may adopt either exploration or exploitation strategies (or both), but their research and innovative activities are loosely related.

(INSERT FIGURE 1 HERE)

3. Empirical design

We examine the evolution of inventive activities that have been performed by universities and firms of Italian NUTS3 regions in recent years to evaluate the incidence of the different co-evolution processes. We expect that different NUTS3 regions will show different dynamics. We thus use the taxonomy to observe the distribution of Italian university-region processes.

Italy represents an interesting case for the understanding of the role of university technology transfer activities in regional specialization processes, due to its peculiar industrial structure, which is mainly composed of SMEs operating in medium-tech industries and within traditional industrial districts. During the period under scrutiny, Italy also underwent major legislative changes that fostered the Italian academic patenting activity. Before 1989, Italian academic institutions had little control of either their finances or staff, as the university system was centrally administered by the national government. The regulatory framework on intellectual property rights did not include any specific provision for patents developed by academic inventors: universities had no incentive to enforce disclosure or to actively manage or commercially exploit the outcomes of their research (for a detailed analysis, see Baldini et al., 2014; Lissoni et al., 2013).

The introduction of new legislation in 1989 allowed universities to exercise a higher degree of discretion over their curricula, strategic directions, and funding sources. The increased autonomy led to the progressive adoption of more formalized procedures concerning intellectual property as well as the establishment of dedicated internal structures and specialized roles to oversee and coordinate technology transfer activities. The so-called *professor privilege* was introduced a few years later, in 2001. The exclusive right to own inventions originating from academic research was given to the faculty members and universities were no longer entitled to retain it, unless otherwise agreed upon with the inventor. The alleged rationale for such a transfer was to put in place a set of mechanisms and incentives for scientists to commercialize their patented research. In 2005, the norm was reviewed and limited in scope by excluding the applicability of professor privilege to all cases in which the research activity was not financed totally by the internal resources of the academic institution[1].

To understand the mechanisms behind the emergence of specific university-region technological evolution processes in more detail, we have complemented the quantitative analysis, based on patent data, with qualitative analysis on the Turin metropolitan area and the Politecnico di Torino.

3.1 Data

We combine data from multiple sources to perform the analysis of the co-evolution processes in the technological specializations of firms and universities located in the same NUTS3 region in Italy. We collect all the patent applications filed at the Italian Patent and Trademark Office (UIBM) by universities and local firms during the years between 1999 and 2013. We opt to use national patent office data on filings rather than international patent applications to have better coverage of the patenting activities of the universities. We have data on the application and publication number and dates, title, technology sub-classes, application and early-access status, issue number, grant dates, list of applicants and inventors for each patent. Moreover, we gather information on the list of 96 recognized academic institutions that officially belong to the Italian higher education system and which are made available on the Ministry for Education, Universities and Research (MIUR) website. To identify all the patents filed by academic institutions, all the university names are searched in the list of owners on each patent document through a semantic approach. Complementary information on the basic characteristics of universities – such as their geographical location, staff, finances, educational and research activities – is derived from the ETER database. The final dataset includes 140,645 Italian patent applications, of which 2,526 are filed by at least one university.

3.2 Methodology

Since most of the data on Italian patent filings are often not available or incomplete in patent databases, we rebuild structured information on all of the 140,645 patents filed during the years between 1999 to 2013 at the Italian Patent and Trademark Office (UIBM), starting from its public web pages. We exploit data on the assignee city for regionalizing each patent in our sample and associate it to one or multiple geographic areas at the NUTS3 level. Furthermore, we adopt a fuzzy comparison and matching technique that accounts for variations and non-exact matches of owner names as well as semantic query searching procedures to identify all the patent applications filed by at least one Italian academic institution. We then use the Revealed Technology Advantage (RTA) index, based on patent classifications, as a measure of technology specialization. Although named differently, the RTA index was introduced by Balassa (1965) to evaluate the

[1] At the European level, the university regulations and policies governing IPRs are heterogeneous, with a prevalence of institutional ownership and the notable exception of inventor ownership in Italy and Sweden. Previous scientific work highlighted the difficulties in assessing the impact of academic institutions on innovative productivity played by the recent knowledge transfer transformative processes (Geuna and Rossi, 2011). Although there is evidence of an increase in the number of university-owned patents in the period under scrutiny, testing for such legislative changes is not the objective of this paper.

international trade specialization of countries. It has subsequently been applied to units at different levels of aggregation (e.g., firms, geographical areas, countries, etc.) and heterogeneous data sources (e.g., products, patents, etc.) to capture specialization patterns in production (e.g., Iapadre, 2001; Laursen and Salter, 2005) and technology (e.g., Soete and Wyatt, 1983; Cantwell, 1995; Liegsalz and Wagner, 2013). Different scholars have explored both the features and the shortcomings of the indicator in great depth (e.g., Yeats, 1985; Vollrath, 1991; Hinloopen and van Marrewijk, 2008). Laursen (2015) proposed a transformed version of the original index, for use in econometrics and other statistical applications, that is characterized by the desirable property of being symmetric and balanced around its neutral value and of behaving equivalently on both sides of unity.
In line with the extant literature (e.g., Soete, 1987; Patel and Pavitt, 1987; Malerba et al., 1997; Antonelli et al., 2017), we employ an analogous measure, but use patents rather than export flows in order to derive information on the relative advantage of geographical area i in a certain technological domain j, compared to other territories. Accordingly, the RTA index is defined as the proportion of patent applications filed in year t by firms located in geographical area i with technology class j, divided by the total share of patents associated to the same geographical area i with respect to the others. As such, the indicator is equal to zero if there are no patent filings in sector j for geographical area i; it is equal to one when the share of geographical area i in technology j equals its proportion in all the domains (i.e., no specialization is observed); and larger than unity if any relative specialization is detected for geographical area i. The indicator has been computed for all territories (or academic institutions) i, all technologies j in specific periods t using the following specification:

$$RTA_{ijt} = \frac{p_{ijt}}{\sum_i p_{ijt}} \Big/ \frac{\sum_j p_{ijt}}{\sum_i \sum_j p_{ijt}}$$

where p_{ijt} is the number of patent applications in the local area (or the university) i in technology j during period t. We then compute the standardized version of the index, or $NRTA$, that is symmetric around zero, as in Laursen (2015):

$$NRTA_{ijt} = \left(RTA_{ijt} - 1\right)/\left(RTA_{ijt} + 1\right)$$

Therefore, positive values of the adjusted indicator denote that the focal area i is relatively strong (i.e., *over-specialized*) in the specific technological domain j , compared to all the other fields in our sample (Soete, 1987). The $NRTA$ indicator is computed taking into consideration all the IPC sub-classes (at a four-digit level) that corresponded to 642 different technologies. The idea behind this approach is that a patent with a specific sub-class is a signal of the local presence of specific competences and skills. The patents with more than one IPC code have been double counted in the computation of the indicator for each of the corresponding technology sub-classes. It should be noted that the RTA index should neither be interpreted as a measure of absolute strength or weakness nor associated with the meaning of performance. By construction of the measure, each area i is associated to at least one technological field j in which it has a relative advantage and lower instances of the indicator for other sectors, irrespective of its total innovative output. Cantwell and Janne (1999) revealed two drawbacks of the index that might bias comparisons when only a few patents or small geographical areas are used to compute the measure. Despite such limitations, RTA is considered to be a useful tool for evaluating the technical specialization of geographical territories or firms, and it has been employed widely in the recent empirical literature.
Once computed the $NRTA$ for all geographical areas in all technologies and years, we propose a novel approach to better characterize the process of technological specialization and to position university-region pairs in a quadrant of the taxonomy (Figure 1). We generate two indicators: the first one captures the leading role of universities versus firms in entering a new technological field, and the second one measures the evolution of the overall technological distance between the technological portfolios of a given university-region pair.
As far as the first indicator is concerned, the entry of area i is defined as the first year in which the vector of its $NRTA$ becomes greater than zero for the specific IPC sub-class j, thus indicating that the geographical area i is over-specialized for technological domain j. Given the limited number of patent applications filed by universities, we use the count of patents rather than the values of the $NRTA$ index for local academic institutions. Hence, the entry of a university in field j is defined as the first year in which it filed a new patent application associated with the specific IPC sub-class j. The binary variables representing the technological entry for regions and universities are set equal to one for the identified years, until the end of the observation period. Hence, for a given area i and technology j, we may obtain different possible situations on the timing of entry of the university (Table 1).

(INSERT TABLE 1)

We provide details on four different instances of technological-entry that may occur for each technology j in each university-region pair. If we observe that the focal area i becomes over-specialized in technology j , with respect to the other territories (i.e., its $NRTA$ for the IPC sub-class j is larger than zero), for the first time in year t, we then study whether the local academic institution had filed a patent application in the same technology domain j and the time at

which it occurs. The university leads the technological entry whenever its patenting activity in technology j starts before year t (i.e., A-type entry). In such a situation, the academic institution is assumed to pursue exploratory innovation activities. Otherwise, the geographical area leads the technological entry whenever the first patent applications of the local university in technology j are filed in the same year t or afterwards (i.e., B-type entry) or not filed at all (i.e., C-type entry). In these instances, the local university is found to be more prone to use and refine existing knowledge and competences with exploitative innovation activities, whereas local firms tend to show high innovation capabilities. Conversely, if the focal area i does not over-specialize in technology j , with respect to the other geographical areas (i.e., its $NRTA$ for the IPC sub-class j is smaller than zero) for all the years, and the academic institution had filed at least one patent application in the same technology domain j, we consider it to be a technological entry led by the university (i.e., entry type D). The last instance takes place if there is no patenting activity in technology j by the local academic institution and the hosting area i never becomes over-specialized in the same field j (i.e., entry type E).
We build a standardized indicator of technology entry for each university-region pair, based on the ratio between the occurrence of cases over the observed years in which the technological entry is led by the university (i.e., types A and D), divided by those in which it is led by the geographical area (i.e., types B and C). Using such a measure, we are able to classify a specialization process as a region-pull versus university-push one. As far as the indicator of technological distance is concerned, we implement the standard Euclidean technological distance measure proposed by Jaffe (1989). Moreover, we compute the distance in a given time t using the following specification:

$$D_t^{RU} = 1 - \sqrt{\sum_j \left(s_{jt}^R - s_{jt}^U\right)^2}$$

where D_t^{RU} is the technological distance between the geographical area r and the local university u, s_{jt}^R and s_{jt}^U are the share of patents of the territory and of the university for technology class j in time interval t respectively. By observing the variation in the distance measure over time, we are able to classify the university-region evolution process as a convergent versus divergent one. Finally, the joint use of the indicator on technological entry and the indicator on the variation in time of the technological distance allows us to classify a specific university-region technological evolution process in one of the four quadrants (Figure 1).

4. Results

4.1 Evidence on the co-evolution of technological trajectories

In this section, we discuss the summary evidence on the evolution of both patenting activities and technology specializations of the examined Italian NUTS3 regions and universities using the set of indicators illustrated in the previous section. Tables A1 and A2 in the Appendix report the number of patent applications and technology specializations for the first 25 geographical areas at the NUTS3 level, according to the total number of patent filings. The data reveal a substantial heterogeneity, even among the best performing territories.

The Turin area is the third-ranked geographical location for the number of patent filings and fourth in terms of the count of technology specializations defined with the $NRTA$ indicator. Furthermore, Politecnico di Torino is ranked third for the number of patent applications, after Politecnico di Milano, and Università degli Studi La Sapienza (that is located in Rome). In terms of specializations, Politecnico di Torino shows 57 specializations for the years between 2009 and 2013, of which 23 (40.4%) are in technological fields for which the Turin area is also over-specialized (i.e., it has a $NRTA$ greater than zero).

In Figure A1 in the Appendix, we investigate the dynamics of the overlapping between the specialization of universities and the related geographical areas by comparing two time-intervals (from 2004 to 2008 and from 2009 to 2013). The data suggest that, for some NUTS3 regions, there has been an increase in the specialization technologies of the university which are not common in the hosting area. Turin is one of such cases, as we can observe that the proportion of specializations in common with the local industrial system has declined from 48.8% to 40.4%. We interpret this result, on the basis of our theoretical framework, as evidence of a potential change in the strategy of the university toward a more explorative role.

This result is also confirmed by the evidence on the characteristics of the entry process into new technological domains. The incidence of technological entry over the full time period from 1999 to 2013 that have been led either by the university or the hosting province is reported in Figure 2 of the Appendix. In the case of the Turin area, the incidence of university-led entry is 32%. This is in line with the figures of the Politecnico di Milano (36%) but is significantly higher than the value of the Università degli Studi La Sapienza (21%). More generally, the data again reveal a substantial heterogeneity that might be the result of different combinations of local industrial contexts and university research or technology transfer strategies.

A comparison between the Euclidean distance computed on the patent portfolios for two subsequent time intervals (i.e., from 2004 to 2008 and from 2009 to 2013) is reported in Figure 2 with the aim of obtaining an overview of the dynamics in time of the technology distance between universities and the hosting territories. In particular, we report the evolution of the Euclidean distances computed between the vectors that represent the composition of the technology portfolios for the universities and the related provinces. The horizontal axis refers to the distance for the first group of years (i.e., between 2004 and 2008), whereas the vertical axis reports the distance for the subsequent period (i.e., between 2008 and 2013). In such years, 46% of all the university-region pairs lie above the diagonal of the quadrant (i.e., the blue-colored dots), thus indicating that the distance increased from the first to the second group of years. A technological divergence process is in place for such academic institutions. The university-region pairs that lie closer to the origin of the quadrant are those for which the distance is relatively lower, while those in the upper-right corner are those for which the technological distance is relatively larger. It should also be noted that the dispersion of points around the diagonal of the quadrant becomes larger as the starting distance between the technology specializations of the geographical area and the local university increases. This result might suggest a presence of heterogeneous technology co-evolution process in the sample. Among the cases for which the Euclidean distance in the first period was larger (i.e., on the left of the chart), we can observe convergence over time for a sub-sample of all the university-region pairs.

(INSERT FIGURE 2)

We provide a comprehensive view of the co-specialization process by integrating the information on the technological entry leadership with the dynamics of the technological distance indicators (Figure 3). The growth of the technological distance between the second (2003-2008) and the third (2009-2013) groups of years is reported on the horizontal axis. The ratio of the number of entries in new technologies led by the university, divided by the entries for which the geographical area became specialized before (e.g., the antecedence ratio), is shown on the vertical axis. The two gray lines are the median values for both dimensions and divide the plane into four separate quadrants. Interestingly, we obtain a distribution of the examined universities across all four quadrants.

(INSERT FIGURE 3)

Quadrant B (at the top-right of the chart) accounts for 18% of all university-region pairs. According to our framework, such areas have a tighter innovation ecosystem, in which local firms show a high absorptive capacity, and the academic institutions are more engaged in activities of technology exploration. It is more likely, for local universities, to push entry into new technologies and to decrease the technology distance from the province over time. Quadrant D (at the bottom-right of the chart) accounts for a larger share of academic institutions (32%) that operate in a loose innovation ecosystem, where local firms have a low absorptive capacity and the universities are active in endeavours of technology exploration relative to the local context. In these university-region pairs, it is the academic institution that is more likely to drives entry into new technologies and the technology distance increases over time. Moving to the left of the graph, roughly a quarter (28%) of all the university-region pairs are located in quadrant A (at the top-left of the chart). Such academic institutions are more involved in technology exploitation efforts and interact within a tight innovation ecosystem where local firms tend to have high innovation capabilities. The remaining universities (22%) are classified in quadrant C (at the bottom-left of the chart), where the role played by academic institutions is either that of exploration or exploitation and local firms are characterized by high innovation capabilities in a loose innovation ecosystem.

The taxonomy and its operationalization offer interesting evidence and call for the investigation of the location-specific factors that might have influenced the emergence of such diverse patterns. In this perspective, the data retrieved for the Turin area seems to be coherent with historical evidence pointing to the presence of a strong industrial focus that has progressively been shifting toward a more diversified portfolio of skills and firms. The local technical university seems to have played an important role in this reconfiguration process by moving from a strong exploitation intent position, based on leveraging on the local industrial know-how, toward a more exploratory strategy that has the potential to support the local emergence of new industries. Such insights from patent data suggest the importance of a deeper assessment of both the underlying institutional characteristics and the impact of specific technology transfer initiatives.

5. The case of technology transfer at the Politecnico di Torino

With the aim to have a deeper understanding of the underlying strategies behind the university-region technological co-evolution processes in Italy, we have considered the perspective of the Politecnico di Torino, with respect to its NUTS3 region, as a single case study. More precisely, we have analyzed how the technology transfer policies that the university decided to put in place between 1999 and 2013 influenced the technological specialization of the local ecosystem and the SMEs that are part of this ecosystem.

Decisions taken by the Politecnico di Torino give a meaningful representation of the strategies by which Italian universities played a role in creating technological trajectories within their territories. They represent how Italian universities gave a relevant contribution to the technological development and specialization of their hosting geographical areas. Such decisions require changes in internal organizations, and their implementation over the years has had to take into account the need to adapt to the evolution of the specific conditions of the local and national economy.

To conduct this case study, we employed structured interviews with some of the key actors involved in the technology transfer activities in the last fifteen years. The collected data were triangulated by examining internal and official documents. Furthermore, we used archival documents, newspaper articles, and web sources to retrieve data regarding strategic regional plans.

5.1 University-region relationship before 1999

Up to approximately 1990, Turin was an industrial metropolitan area characterized by the presence of the Fiat (now FCA) carmaker and other large companies like Telecom Italia, Leonardo, Thales, Comau and Magneti Marelli (Whitford and Enrietti, 2005; Colombelli, 2006; Quatraro, 2007; Colantonio et al., 2013; Colombelli et al., 2019). Moreover, a large chain of small businesses had clustered around these large companies, operating in such industrial sectors as the automotive, aeronautics, telecommunications and textile sectors. The geographical area has thus developed high innovation capabilities over time in those areas of specialization and built up a strong network of relationships among the local industrial actors.

At that time, the role of the Politecnico di Torino, in terms of knowledge and technology transfer, was mainly based on informal technology transfer activities. Originating in 1859 as the *School of application for Engineers*, the first mission of Politecnico di Torino was to transmit knowledge within the local ecosystem through highly educated and skilled individuals in the technological areas of regional specialization. Another mechanism of technology transfer was the cooperation of Politecnico di Torino in the research projects of large firms. However, collaborations were mainly the result of agreements between individual researchers and large firms, aimed at solving their specific technical problems. Generally, the intellectual property rights resulting from the joint development of new technologies were fully appropriated by the industrial partners, who used them to create new products and processes.

During the nineties, the Turin area underwent a profound transformation, due to many external factors: the Fiat crisis, the prolonged crisis of the Italian economy, the increasing international competition together with the contemporary decline of traditional industries, and the rise of the so-called knowledge-based economy. Large companies started to move their productions to other countries and the pool of SMEs and the entire economy of Turin were consequently affected to a great extent by this crisis.

5.2 The years between 1999 and 2003

In this period, the Politecnico di Torino made the first attempts to introduce formal technology transfer activities by creating a dual structure to combine exploitation and exploration strategies. Its strategy complemented decisions taken by the regional government through its strategic plan[2], which defined priorities in terms of regional specializations. It recognized that the university system played a key role in this technological specialization process.

In line with such a regional strategic plan, the Politecnico di Torino adopted several actions. The first one was to build more formal collaborations with local firms (e.g., collaborative research, contract research, consulting, joint ventures, etc.). The university founded two different research centers (ISMB[3] in 2000, and SITI[4] in 2002) in partnership with large companies (e.g., *Telecom Italia*, *Motorola*, *Fiat*, *ST Microelectronics*, etc.) and local public institutions. The mission of such centers was to develop applications of Internet-based technologies in those SMEs that were active in traditional sectors and in such areas as logistics, territorial safety, environmental protection, and urban renewal. The DIADI[5] project – which had the aim of diffusing the adoption of new technologies and new manufacturing processes to renew large declining industrial areas and its SMEs – and the foundation of the I3P incubator – a non-profit joint-stock consortium that included the Politecnico di Torino, the Chamber of Commerce, the City and the Province of Turin as shareholders – were other key initiatives. The incubator had the clear mission of sustaining the local economy by promoting the creation of technology-based start-ups that could valorize and commercialize the results of academic research.

However, the commercialization of research through patenting was still limited during this period, and the large industrial partners kept most of the ownership of intellectual property rights resulting from collaborative research projects.

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[2] Documento unico di Programmazione (DOCUP) for the years between 2000 and 2006.
[3] *Istituto Superiore Mario Boella*.
[4] *Istituto Superiore sui Sistemi Territoriali per l'Innovazione*.
[5] *Diffusione dell'innovazione nelle aree a declino industri*ale.

5.3 The years between 2004 and 2013

In this period, different external factors influenced the overall approach of the Politecnico di Torino to technology transfer and led it to the next stage of evolution through a mix of exploitation and exploration. First, the change in the Italian legislation on patents and university spinoffs (2005) greatly facilitated the patenting activities of all national universities. At the regional level, under the new strategic plan, the government sponsored the creation of new technological industry-wide programs (called *platforms*) to perform industrial and applied research aimed at promoting collaboration between local universities and firms. As a complement to the platform policy, the local Piedmont government also promoted the development of innovative clusters in selected industrial areas[6]. These clusters had four main objectives: funding support to sustain SME investments, technology transfer to SMEs, networking, and research on key enabling technologies.

In line with these regional policies, the Politecnico di Torino progressively changed its approach to patents, introducing co-ownership practices for collaborative research, and introduced new formal procedures to better manage research collaboration and contract research, up to the creation of joint ventures with large companies. Another key initiative was the creation of a Business Research Center, aimed at locating the research laboratories of local and international firms (e.g., *General Motors*, *Pirelli*, *Microsoft*, *Vishay*, etc.) within the university campus to support the cross-fertilization of knowledge from different domains. Overall, these actions were consistent with the exploitation strategy of the Politecnico di Torino, which was aimed at leveraging on knowledge accumulated over time at the local level through applied research projects developed in collaboration with local firms. Such an approach contributed to strengthening the network of relations within the local ecosystem and to increasing the technological proximity between the university and local firms.

At the same time, the Politecnico di Torino started its exploration activities with local companies, in order to help them enter into new technological specializations. On the one hand, the strategy was consistent with local policies. The focus of both the platform and cluster regional policies was in fact not only devoted to traditional industries (e.g., *automotive* and *aerospace industries*) but also toward new emerging fields (e.g., *biotechnologies*, *health sciences*, and *mechatronics*) to generate cross-fertilization between traditional and new industries. On the other hand, the exploration approach of the Politecnico di Torino was consistent with the objective of stimulating excellence in research promoted by the European Commission. The university started exploring and developing new technologies and competencies (e.g., nanomaterials, bioengineering, energy storage, etc.), by conducting research projects financed within the Sixth and Seventh EU Framework Programs.

The effect of this new wave of exploration was a growth in the entry of new technological specializations led by the university as well as the increased technological proximity between the Politecnico di Torino and its hosting geographical area, as suggested by the evidence on patents provided in the previous section. However, a limit of the new strategies adopted by the Politecnico di Torino and the local government was that local SMEs were still at the margin of this technological evolution process.

As far as the more recent years are concerned, the availability of recent data on the technology transfer activities of the Politecnico di Torino has revealed a steady growth in the number of filed patents, covering a larger spectrum of technical specializations[7], a growth in spinoffs, a superior ability of spin-offs to raise early-stage funding from investors and local companies, as well as an increase in the number of partnership agreements with both large and small companies. The creation of cross-department research centers – focused on new breakthrough technologies (e.g., *additive manufacturing*, *applied photonics*, *water technologies*, *artificial intelligence*, and *big data*) that are able to share research infrastructures with both large companies and SMEs operating in their supply chain – as well as the launching of a Proof-of-Concept program offers further support of the effective exploration of new technological trajectories at the territorial level.

However, due to a lack of data on patenting activities at the NUTS3 level in the period after 2013, it is still not possible to analyze the impact of the new wave of technology transfer activities that have been implemented by the Politecnico di Torino. Future research may provide further evidence on the Turin university-region technological evolution process.

Summing up, the case study shows how the Politecnico di Torino and its geographical area have co-evolved, over a period of twenty years, from a traditionally industrial territory to a region with more sophisticated and technologically-diversified companies. As shown by the empirical evidence, such a process has been characterized by increasing technological proximity between the university and the local firms. The process has apparently been pushed by research activities conducted by the university which have then been transferred to local firms with a high absorptive capacity. The academic institution has moved from a strong exploitation strategy, based on the leverage of the local industrial know-how, toward a more exploration strategy which involves supporting the local emergence of new industries.

[6] Among the others, Agrifood, Biotechnologies and Biomedical, Renewable Energies and Biofuel, ICT, Sustainable Chemistry, New Materials, Mechatronics, and Advanced Production Systems.

[7] From 34 unique IPC classes in the 2009-2013 period to 42 in the 2014-2017 period.

6. Discussion and conclusions

This paper has explored the dynamics by which Italian universities are contributing to the local technological development and the specializations of the territories where they are hosted.

To this aim, the co-evolution of the technological trajectories of Italian NUTS3 areas in Italy and the corresponding universities has been analyzed through the use of patent data. Moreover, to examine how factors at the university, firm, and ecosystem levels affect the university-region technological evolution processes, we have provided an original taxonomy based on two dimensions (i.e., convergent versus divergent and region-pull versus university-push processes) and have identified four possible models.

The taxonomy and its operationalization have revealed substantial heterogeneity in the identified university-region specialization processes, which might be the result of different combinations of local industrial contexts and university research or technology transfer strategies. In this respect, the conceptual framework developed in the paper has taken into account the role of local contingent factors (at the university, firm, and regional level) in the dynamics of knowledge transfer within the ecosystem. The paper, thus, contributes to the literature under three lines. First, it provides new insights to the literature on the ambidexterity of universities (Gibson and Birkinshaw, 2004; Raisch and Birkinshaw, 2008; Tushman and O'Reilly, 1996). Our results show that the combination of exploration and exploitation strategies supported by dual structures within academic institutions can exert a leading role in regional technological evolution processes. Second, the paper contributes to the literature on absorptive capacity and regional innovation systems (Boschma, 2005). According to our framework, the absorptive capacity of firms may affect the effective transfer of knowledge from universities to local firms. Third, the paper contributes to the literature on university-industry links (Braunerhjelm, 2008). Our framework supports the idea that the transfer of complex knowledge is affected by the technological proximity of economic agents within the local system. In providing guidelines for the development of new technological trajectories for regions, policymakers should take into account the heterogeneous outcomes of increased collaboration between firms and local universities that might stimulate a steady co-evolution process of convergence between their technological specializations. This effect might be especially true when considering industrial sectors characterized by the presence of technical standards or complex product structures (e.g., *semiconductors*, *telecommunications*, *software*, etc.) in which the positive effect generated by the entry of academic institutions is likely to be more geographically bounded. On the one hand, the hypothesis that the technological proximity between the innovative endeavours of universities and those of the hosting territories increase the likelihood of specialization for local companies seems to be in line with the policies based on the concept of the *Smart Specialization Strategies* (S3) according to which the most successful regions are those that build comparative advantages, identify strategic areas of intervention, direct their innovative efforts on the basis of their idiosyncratic capabilities, cumulated knowledge, and distinctive assets (Boschma, 2014; Foray, 2009, 2014). However, universities should be equally supported by central governments in their exploration activities and basic research in order to mitigate the detrimental but intrinsic lock-in effects of strategies based on regional diversification patterns. In fact, the technological entry of academic institutions in fields for which local firms are not yet over-specialized may well contribute to the development of new knowledge and competencies in the hosting region that might not emerge otherwise because of the path-dependent nature of technological co-evolution processes.

To provide a deeper understanding of these dynamics, we have illustrated the specific case of Turin, by taking into consideration the perspective of the Politecnico di Torino. On the one hand, the evidence from the case study suggests that the combination of both exploitation and exploration strategies may contribute to increasing the technological proximity of universities and local firms by leveraging on local knowledge and competencies. On the other hand, it may also support the regional branching process through the emergence of new industries.

From this case, two findings that we deem to be relevant for future research and which show the specificity of technology transfer in Italian universities have emerged. The first aspect regards the different stages of co-evolution and a shift in leadership. The case study gives micro-level insights about how universities could take the lead in determining exploitation and exploration strategies in Italian NUTS3 areas, compensating for the role of large companies and investing in technologies that are the basis of local specialization. Secondly, when the role of incumbent (mainly large) firms becomes less relevant, universities may add exploratory strategies aimed at supporting the emergence of new industries to already existing exploitation strategies, based on the leverage of the local industrial know-how.

More in general, the findings concerning our analysis can be generalized to other universities and geographical areas. In this respect, the descriptive evidence on both the technological evolution and specialization of European universities and territories can help identify those geographical areas for which Turin represents a useful benchmark. Moreover, the availability of data at the European level allows our methodology to be extended for conducting larger cross-national studies. A limitation of our empirical analysis is related to the data sources that we employ to assess and characterize the dynamics of the technological specialization processes for both regions and universities. We exploit information available in national patent applications filed at the UIBM to build our indicators of technological distance and specialization. Such a choice is motivated by the need of having the largest and most detailed coverage of all innovation activities performed by local academic institutions and companies. Although this data source is rich and representative of the whole population of inventions developed within the national borders (i.e., about 80% of all patent applications filed by national universities have a domestic priority country), unfortunately it is not complete. An extension of the relevant sample of patents through the inclusion of applications filed at the European Patent Office (EPO) by Italian firms and academic institutions would further improve the accuracy of the measures used in the taxonomy and help to alleviate potential selection issues related to the heterogeneous quality of the patented technologies (i.e., extending the legal protection in other jurisdictions requires the payment of additional fees that are justified only if the underlying technology is of higher value). Future work could also extend the time window to consider more recent years, use additional controls at the university and region level (e.g., the share of co-assigned patents, the industry structure, etc.) as well as collect data on scientific publications and public funding. We did not include in the portfolio of technologies developed by local academic institutions those patents having university scientists among the list of inventors but not the parent organization among the assignees (i.e., the so-called *academic patents*). Such a measurement problem could potentially introduce biases in all our measures, leading to a lower technological entry and a higher distance. However, it may be not much relevant for Italy (i.e., since the university is reported in the list of patent owners in most of the cases) as it could be for other countries. Finally, more sophisticated econometric analyses could be employed to shed light on the determinants of university-region technological co-evolution processes.

Our results may provide important implications for universities and territories outside Italy, to help them develop more integrated exploitation and exploration strategy approach. In this respect, universities should put in place a number of initiatives, including the redesigning of the TTO structure (to strengthen formal relationships between departments and external actors), the revising of the procedures for IP protection and diffusion (to favour the appropriation of the returns from scientific research), the sharing of research infrastructures on break-through technologies and the introduction of Proof-of-Concept programs (including funding support, services focused on go-to-market analyses, and mentorship from local entrepreneurs and investors) to further support and accelerate the valorisation of academic research. This is a difficult path that requires a wide array of changes regarding the allocation of internal resources, support from the regional government, the ability to simultaneously produce high-quality research (to be published in international journals), and to stay close to medium-tech industries and SMEs. Moreover, the case study of the Politecnico di Torino suggests to university managers and policy makers that the process of building an “ambidextrous university” requires time and a deliberate allocation of resources (Cesaroni and Piccaluga, 2016). Future research could extend such analysis into other regions by investigating qualitatively and quantitatively how university and regional technological specializations have evolved over time. This could be done by exploring, for instance, the activities undertaken by key economic actors in the region and alternative or more sophisticated measures of the technological distance between firms and universities. Finally, the paper provides further evidence of the role of universities in supporting innovation in both new and existing technological specialization. In this respect, this paper recommends to policy makers at EU level the inclusion of universities and research organizations in the framework of the European Innovation Council as potential sources of disruptive and breakthrough innovations, which seems to be excluded in the current pilot program (Weber et al., 2019).

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TABLES AND FIGURES

Table 1 – Classification of technology-entry instances

Entry type	NRTA of the geographic area i greater than zero in technology j and year t	Patent activity of the university in technology j	Entry classification
A	Yes	Yes, before year t	University led entry
B	Yes	Yes, in year t or after	Area led entry
C	Yes	No	Area led entry
D	No	Yes	University led entry
E	No	No	No entry

Figure 1 – Taxonomy of university-region technological evolution processes

Evolution process	*Region-pull*	*University-push*
	QUADRANT A	**QUADRANT B**
Convergent	- Exploitation role of university - Local firms with high innovation capabilities - Tight innovation ecosystem	- Exploration role of university - Local firms with high absorptive capacity - Tight innovation ecosystem
	QUADRANT C	**QUADRANT D**
Divergent	- Either exploration or exploitation role of university - Local firms with high innovation capabilities - Loose innovation ecosystem	- Exploration role of university - Local firms with low absorptive capacity - Loose innovation ecosystem

Figure 2 – Evolution of the Euclidean distance between universities and NUTS3 areas

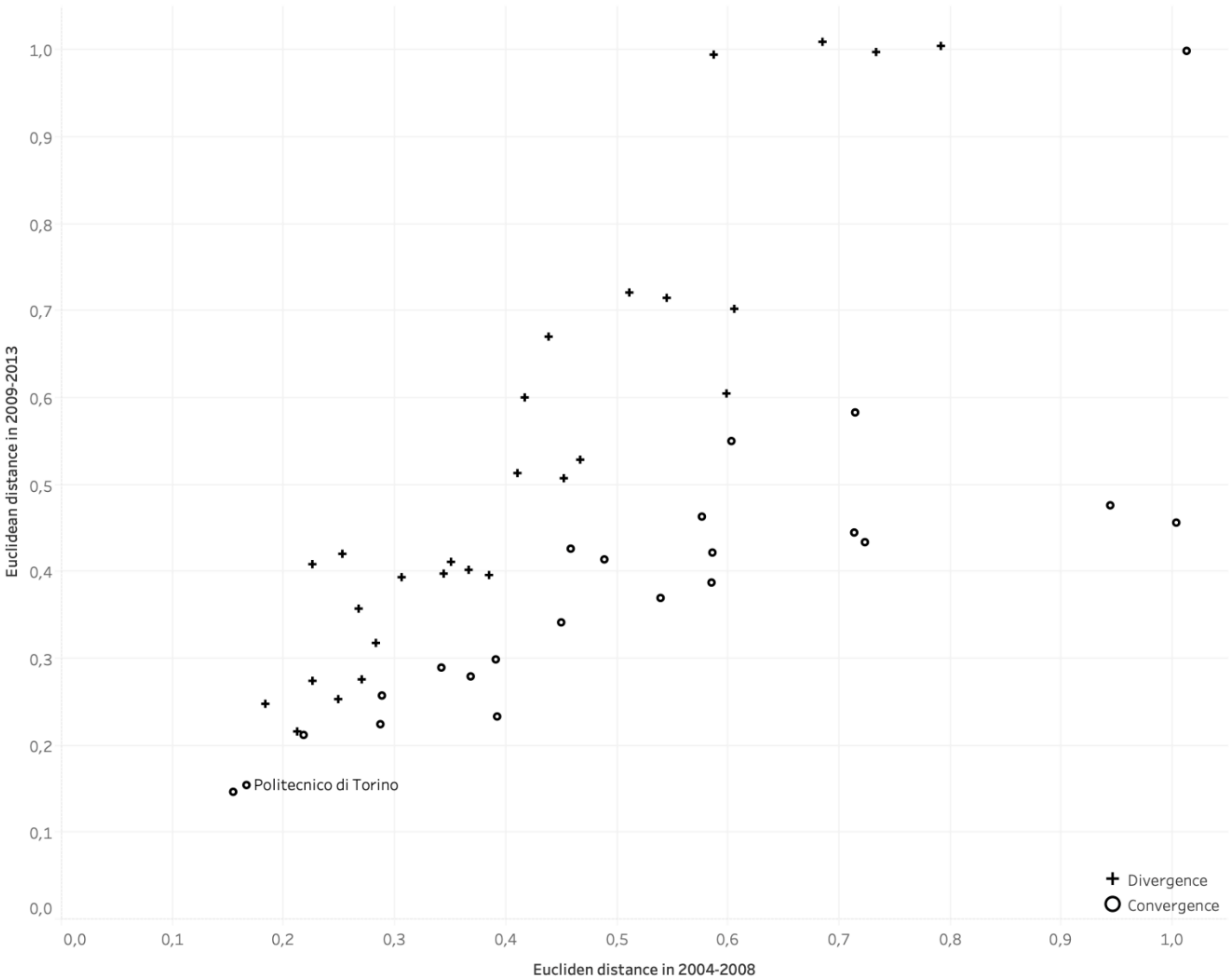
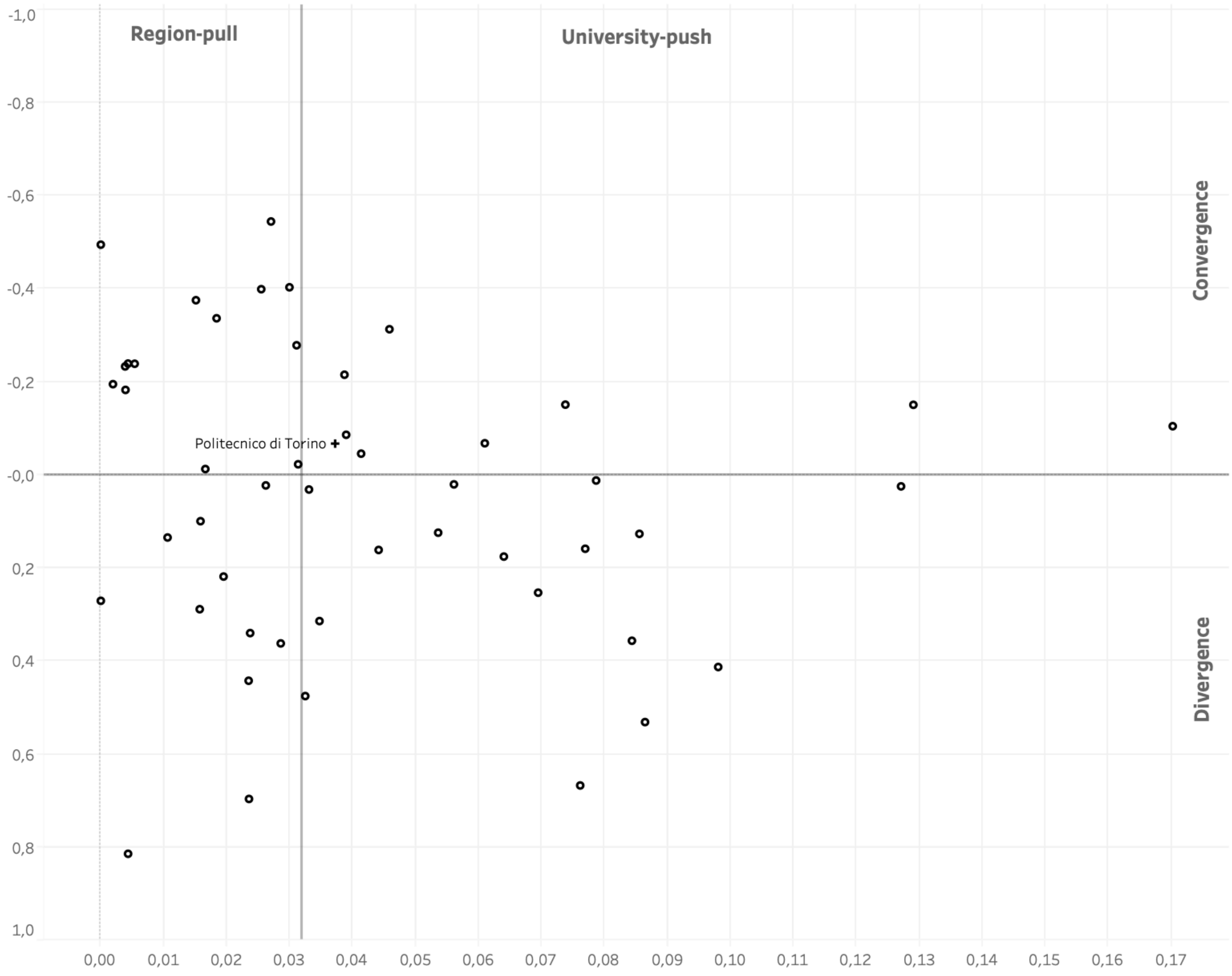


Figure 3 – Taxonomy of university-region technological evolution processes: region-push versus region-pull, convergent versus divergent



Appendix

Table A1 – Patent applications and technology specializations by NUTS3 area and group of years (first 25 areas by total patent applications)

Area rank	NUTS3 area	Pat. appl. (total)	Pat. appl. (09-13)	Technology specializ. (09-13)	Reg. innov. score index (2017)
01	Milano (ITC4C)	11,910	2,697	207	81.646
02	Bologna (ITH55)	6,425	1,681	138	81.977
03	Torino (ITC11)	5,721	1,434	161	81.854
04	Roma (ITI43)	5,006	1,354	187	75.522
05	Vicenza (ITH32)	4,809	1,176	151	81.458
06	Treviso (ITH34)	3,880	1,045	125	81.458
07	Modena (ITH54)	3,746	940	128	81.977
08	Brescia (ITC47)	3,292	1,057	147	81.646
09	Padova (ITH36)	3,234	910	161	81.458
10	Firenze (ITI14)	2,583	824	136	77.458
11	Bergamo (ITC46)	2,562	747	141	81.646
12	Reggio Emilia (ITH53)	2,453	635	120	81.977
13	Verona (ITH31)	1,963	549	132	81.458
14	Varese (ITC41)	1,793	479	126	81.646
15	Ancona (ITI32)	1,700	598	93	71.188
16	Genova (ITC33)	1,662	458	137	71.402
17	Udine (ITH42)	1,632	390	99	90.151
18	Monza Brianza (ITC4D)	1,626	753	109	81.646
19	Parma (ITH52)	1,554	401	98	81.977
20	Pordenone (ITH41)	1,303	295	92	90.151
21	Como (ITC42)	1,258	373	102	81.646
22	Mantova (ITC4B)	1,203	303	101	81.646
23	Pesaro Urbino (ITI31)	1,198	313	96	71.188
24	Napoli (ITF33)	1,170	294	121	59.308
25	Venezia (ITH35)	1,139	300	108	81.458

Table A2 – Patent applications and technology specializations by university and group of years (first 25 universities by total patent applications)

Univ. rank	University name	Area NUTS3	Pat. appl. (total)	Pat. appl. (09-13)	Tech. spec. (09-13)[1]	Pat. prod. (09-13)	Univ. staff (FTE)
01	Politecnico di Milano	ITC4C, Milano	287	122	59 (27)	0.050	2,443
02	Uni. La Sapienza di Roma	ITI43, Roma	177	67	30 (23)	0.016	4,122
03	Politecnico di Torino	ITC11, Torino	162	92	57 (23)	0.093	985
04	Uni. di Bologna	ITH55, Bologna	140	40	24 (5)	0.113	3,550
05	Uni. di Milano	ITC4C, Milano	123	30	19 (12)	0.010	3,149
06	Uni. di Pisa	ITI17, Pisa	109	41	20 (9)	0.016	2,543
07	Uni. di Padova	ITH36, Padova	89	40	26 (11)	0.010	3,961
08	Uni. di Torino	ITC11, Torino	87	43	26 (8)	0.016	2,774
09	Scuola Super. Sant'Anna	ITI17, Pisa	79	55	18 (10)	0.293	188
10	Uni. di Genova	ITC33, Genova	59	30	19 (10)	0.014	2,077
11	Uni. di Palermo	ITG12, Palermo	58	26	21 (5)	0.012	2,125
12	Uni. di Salerno	ITF35, Salerno	55	19	16 (5)	0.017	1,137
13	Uni. di Udine	ITH42, Udine	54	13	9 (1)	0.126	1,030
14	Uni. Tor Vergata di Roma	ITI43, Roma	50	9	7 (6)	0.005	1,682
15	Uni. di Firenze	ITI14, Firenze	48	12	7 (2)	0.006	2,023
16	Uni. di Siena	ITI19, Siena	46	8	6 (3)	0.005	1,462
17	Uni. Bicocca di Milano	ITC4C, Milano	43	25	15 (9)	0.022	1,138
18	Uni. di Trieste	ITH44, Trieste	41	13	10 (3)	0.013	986
19	Uni. della Calabria	ITF61, Cosenza	38	18	14 (3)	0.017	1,057
20	Uni. di Ferrara	ITH56, Ferrara	34	10	7 (3)	0.010	1,006
21	Uni. di Pavia	ITC48, Pavia	29	9	8 (4)	0.068	1,330
22	Uni. Federico II di Napoli	ITF33, Napoli	27	2	2 (1)	0.001	2,813
23	Uni. Aldo Moro di Bari	ITF47, Bari	27	7	4 (2)	0.004	1,933
24	Uni. di Brescia	ITC47, Brescia	26	9	7 (1)	0.009	1,013
25	Uni. Roma Tre	ITI43, Roma	26	12	11 (9)	0.010	1,239

[1] The number of specializations in common with the associated local area (NUTS3) is reported in brackets

Figure A1 – Number of technology specializations by type and group of years (firm 25 universities by total number of technology specializations)

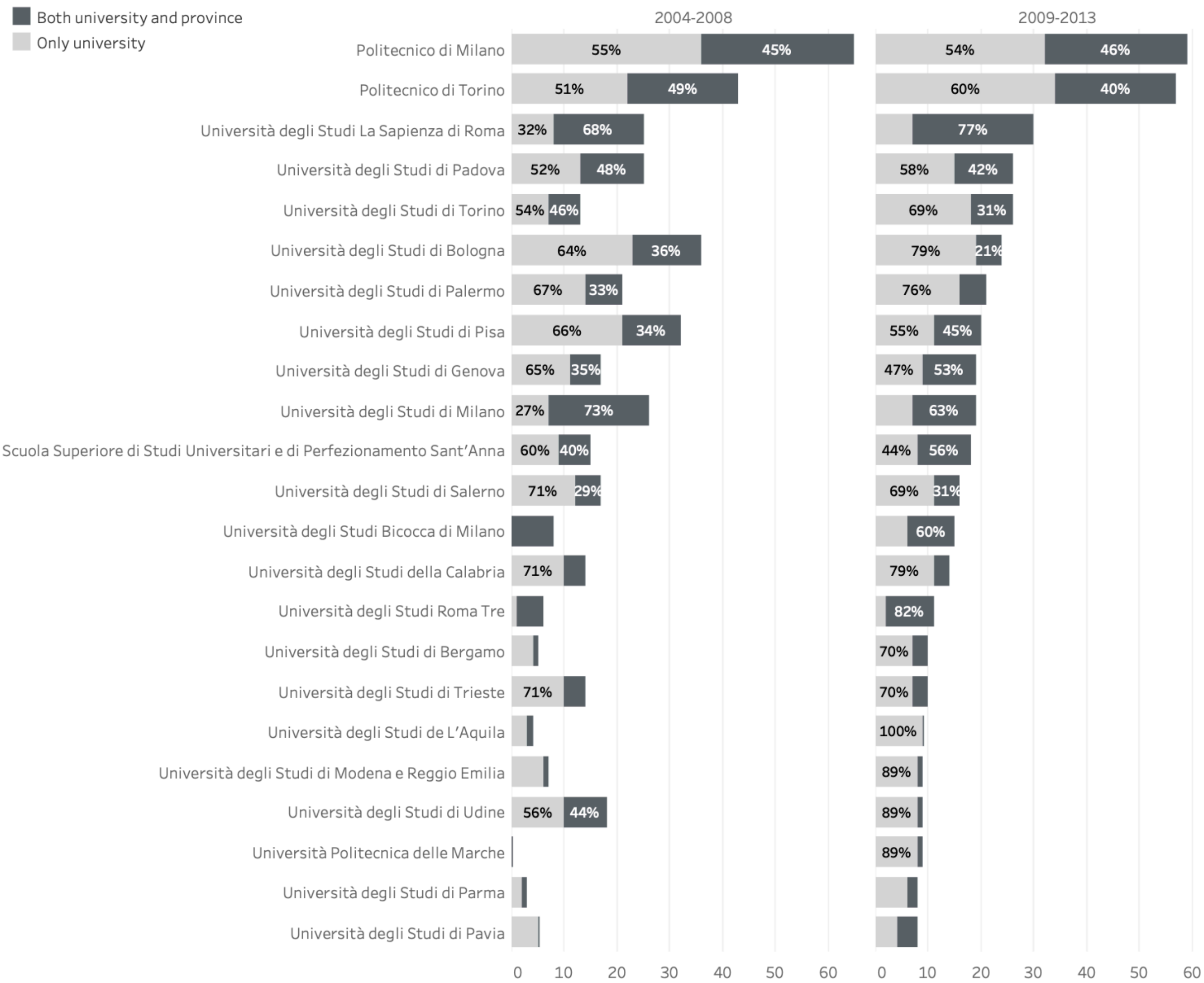


Figure A2 – Technological entry over the period from 1999 to 2013