CIMR Research Working Paper Series

Working Paper No. 30

Academic Inventors: Collaboration and Proximity with Industry

by

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29 February 2016

ISSN 2052-062X

Abstract

This paper addresses a number of fundamental research questions on university-industry (U-I) collaborations. Are U-I collaborations intrinsically different from other forms of collaboration, such as inter-firm or inter-university collaborations? Are they more difficult to form? Is their output qualitatively different? What factors facilitate their development? By looking at the collaborative behavior of all Italian inventors over the 1978-2007 period, the empirical analysis shows that U-I collaborations are less likely to happen when compared to other types of collaboration, and suggests that they tend to generate patents of more general applicability in subsequent inventions. As emphasized by the literature, geographical proximity plays an important role in facilitating all forms of collaboration. At the same time, it works as a possible substitute for institutional proximity, facilitating U-I collaborations. However, the involvement of 'star inventors' on both sides of the collaboration can play an equally important role in 'bridging' universities and industry.

***Key words**: university-industry collaboration; institutional and geographical proximity; innovation; regions.*

***JEL Classification**: O31, O32, O33, R10*

Acknowledgements

This research has been supported by the Marie Curie Intra-European Fellowship project FP7-PEOPLE-2011-IEF-298167-REGIO_SPIN, under the EC Grant Agreement No: PIEF-GA-2011-298167. We also acknowledge support from the project on "Industry and University linkages" funded by Roma Tre University (Italy). The authors would like to thank Francesco Lissoni, and the participants in the research seminar at the Group of Theoretical and Applied Research in Economics (GREThA) of the University of Bordeaux, May 2014; in the Workshop on University-Industry Linkages at the Department of Economics of Roma Tre University, May 2014; and in the NARSC Conference 2014 in Washington. The authors are solely responsible for any errors contained in the article.

1. Introduction

Over the past fifteen years university-industry (U-I) linkages have attracted increasing attention from both scholars and policy makers. The progressive abandonment of the 'linear model' in favor of more sophisticated systemic and interactive approaches to the genesis of innovation has produced a shift in both analytical and policy targets. The spotlight moved from basic science, general purpose technologies and various forms of Research and Development (R&D) efforts to the relations and linkages between a variety of agents (firms, public research centres, universities, etc.) collectively forming local, regional, national or supra-national innovation systems (e.g. Archibugi 2001; Verspagen, 2006) and contributing to regional development (Lawton Smith and Bagchi-Sen, 2010). Scholars and policy makers have come to the realization that leveraging public and private investment in R&D is not necessarily leading to stronger regional or national innovation performance, unless these efforts are supported by adequate systemic conditions. However, notwithstanding the conceptual emphasis on the truly systemic multi-actor nature of the innovation process, some specific components of the 'innovation system' have received a disproportionate consideration: this is in fact the case of U-I linkages. Fostered by the appeal of the 'triple-helix' approach (e.g. Etzkowitz et al. 2000) U-I collaborations have become a *mantra* of innovation policies around the globe.

The strength and extent of U-I collaborations are now universally included among the key indicators to capture the innovation performance of national and regional economies (see, for example, the OECD Science and Technology Indicators or the EU Innovation Scoreboard). U-I collaborations are top priorities in the innovation policy agendas of many governments. When the OECD presented the latest available cross-country data on U-I collaborations[1] in June 2013, countries at the bottom of the ranking immediately reacted in order to make up for their weakness. For example Australia - among the top-ten OECD countries for innovation performance - ranked last (33rd) for the proportion of businesses collaborating with higher education and public research institutions. This fuelled an intense internal debate that culminated in March 2015 with the publication of a new innovation strategy report on "Ensuring Australia's Future Competitiveness through University-Industry Collaboration" (PwC, 2015). But a similar faith in U-I collaborations has also been placed by countries in the middle (e.g. the UK, ranked 19th) and lower (e.g. Italy, 26th) positions of the OECD ranking. Out of seven key action-points summarizing the innovation policy of the UK Coalition Government between 2010 and 2015, two are about U-I collaborations (Department for Business, Innovation & Skills, 2015). Even if Italy lacks an explicit national-level innovation strategy, a significant amount of resources have been earmarked to U-I linkages in the framework of the 'smart specialization strategy', supported by both national strategies and the European Structural Funds (European Commission, 2012).

At both national and sub-national levels support for U-I linkages is presented as a means to achieve two objectives simultaneously: a) facilitate technology transfer and increase technological intensity at the firm level, in particular in less developed regions; b) create incentives for university research to address

[1] OECD, based on Eurostat (CIS-2010) and national data sources, June 2013: http://dx.doi.org/10.1787/888932891359

relevant practical problems, generating market value under the fundamental assumption that 'useful academic research is also good academic research' (Dosi et al., 2006).

A vast scholarly literature has aimed to assess the impact of U-I collaborations on innovation, identify their drivers, and evaluate the corresponding policy tools. In this context, special emphasis has been devoted to the role of geographical proximity and spatial clustering in shaping knowledge transmission between science and business. Empirical research has looked at three main channels, namely: collaborative research projects (e.g. D'Este and Patel, 2007; D'Este at al. 2013), scientific publications (e.g. Abramo et al., 2009; Giunta et al., 2014; Glänzel and Schubert, 2005), and patenting (e.g. Balconi and Laboranti, 2006). All these works have contributed to shed new light on the functioning of U-I collaborations, often questioning the principles on which some of the most common policy tools rest. However, existing research has given for granted the 'special' nature of U-I links as opposed to other possible forms of innovative collaboration (e.g. inter-firm or inter-university collaborations). Even if the latter are also crucial components of the relational dimension of any innovation system, existing research has focused on the formation (or lack thereof) of U-I collaborations, failing to assess them against the broader set of possible cooperative links. Therefore, the literature has so far neglected some key questions such as: Are U-I collaborations intrinsically different from other forms of innovative collaboration so as to deserve special attention and support? Are they more difficult to form? Are they more 'valuable' (Giuliani and Arza, 2009)? What factors make them more or less likely to develop?

This paper addresses these research questions by analyzing U-I as one of the possible forms of collaboration between inventors. All collaborations are shaped by both individual-level characteristics and preferences and by relational factors between possible collaborators. Conditioned upon individual characteristics the probability of collaboration is shaped by geographical, institutional, social or cognitive proximity between the potential team members involved. In this framework, for U-I collaborations to occur, agents have to overcome the institutional distance between the business world and academia.

The paper is grounded into the micro-level literature on the different types of relational factors, and in particular geographical, social, or organizational proximity among inventors (Agrawal et al. 2008; Boschma and Frenken, 2010; D'Este et al., 2013; Crescenzi et al. 2016) that shape collaborative behavior. The analysis looks at the case of Italy, characterized by high heterogeneity in terms of both innovative dynamisms and attitude towards cooperation (Crescenzi et al., 2013), and by the dominance of a 'Personal Mode' of research collaboration that supposedly compensates for the limited technology transfer via 'Institutional Mode' (Boidas Freitas et al., 2013; Geuna and Rossi 2013).

The empirical strategy is based on the comparison between actual collaborations and a control group of 'virtual' collaborations (i.e. teams that given their characteristics should be formed but in fact are not). The dataset covers all patents application filed by Italian inventors between 1978 and 2007 and identifies academic inventors by means of information provided by the Italian Ministry of Education. The results confirm that collaborations between business and academic inventors are indeed hindered by the lack of institutional proximity that instead supports inventors within inter-firm or inter-university collaborative networks. The analysis also suggests that, once established, U-I collaborations lead to patents of more general applicability. Geographical proximity facilitates U-I collaborations, though the involvement of 'star inventors' on both sides of the U-I collaboration can play an equally important role in 'bridging' business and academia.

The paper is organized as follows. The next section summarises the background literature on U-I linkages and the different forms of proximity. Section three explains data and empirical strategy, and provides some descriptive statistics. The results are presented in section four, whilst the concluding section offers some implications for policy.

2. University-Industry linkages and collaborative invention

2.1 Linkages, proximities and innovative collaborations

Collaborative work has to deal with two orders of problems: the identification of the most suitable partner(s) and the efficiency of the resulting team. Individual inventors (or the entrepreneurs or managers in charge of new projects/laboratories) have to identify the most suitable collaborators/team members, dealing with information asymmetries and signaling effects that increase the complexity of the search and matching process (Ackerberg and Botticini, 2002). Once the team is formed individual efforts are often unobserved (or hard to observe) with free-riding, procrastination, and principal-agent problems (Bonatti and Horner, 2009). Therefore, the analysis of the collaborative behavior of innovative agents has focused on the identification of individual-level (i.e. pertaining to each agent), social (i.e. linked to the socio-economic environment in which individuals are embedded) and relational (i.e. concerning the relative position of the agents in a cognitive or relational space) characteristics enabling collaboration by solving such problems (Breschi and Lissoni, 2006; Agrawal et al., 2008; Muscio and Pozzali, 2013; Kerr and Kerr, 2014; Crescenzi et al., 2016). The relational factors that shape the collaboration between innovators can be conceptualized by looking at five different 'proximities': geographic, institutional, organisational, social and cognitive proximities are all likely to spur cooperative behaviour (Boschma, 2005; Torre and Rallet, 2005; D'Este et al., 2013; Crescenzi et al., 2016). The analysis of the drivers of collaboration patterns is then focused on understanding which proximities are most important for different actors, and how they may or may not interact/complement/substitute for each other.

In this framework, for university-based inventors to collaborate with firm-based inventors (and vice versa) it is necessary to overcome the barrier of the lack of 'institutional proximity' that, instead, would facilitate individuals belonging to the same institutional type (Kirat and Lung, 1999; Hall et al., 2001, 2003). The latter refers to the institutional conditions in which individuals operate[2] and make decisions. Institutions include both formal codes of behavior (such as laws and rules) as well as informal arrangements (e.g. habits, norms, culture). While companies and universities based in the same country share a similar national institutional framework, there are significant differences in the rules governing business and academia. For instance, workers are recruited and evaluated on the basis of completely different norms and regulations. The formal system of incentives and career progression also differs

[2] These should not be confused with relations at the micro level (e.g. friendship) which in turn relate to social proximity (Boschma 2005)

radically. In addition, actors in business and in academia show distinctive features along a number of informal institutional dimensions such as habits, conventions, norms and culture (e.g. Merton, 1973; Dasgupta and David, 1994).[3]

Other proximities between innovative agents co-exist with the institutional dimension. The early literature on innovative collaborations has extensively focused on geographical proximity as a key enabler for knowledge exchange and collaboration (Jaffe, 1989; Jaffe et al., 1993; Mansfield and Lee, 1996; Feldman, 1999; Arundel and Geuna, 2004; Abramovsky et al., 2007; D'Este and Iammarino, 2010; Feldman and Kogler 2010; Laursenet al., 2011). Spatial proximity facilitates the exchange of new complex non-codifiable knowledge via face-to-face contacts, making communication more effective due to trust and social engagement (Storper and Venables, 2004). These latter factors are clearly relevant to both partner selection and the success and productivity of the resulting collaboration. However, as highlighted by an equally vast literature (e.g. Malmberg and Maskell, 2002; Howells, 2002; Gertler, 2003; D'Este et al., 2013), geographical proximity can be complemented or replaced by other proximities in supporting information and knowledge sharing . The position of the actors in networks generates a social proximity that might spur collaboration and knowledge exchange across institutional and spatial boundaries (Breschi and Lissoni, 2001). Cognitive proximity – defined as common knowledge bases, similar and complementary bodies of knowledge that allow to understand, process, and exchange new knowledge (Nooteboom et al., 2007) – is also important to reduce the "distance between the academic and industrial realms" (Balconi et al., 2004, 128). Also important for collaboration is organizational proximity: the set of relationships between and within organization "connected by a relationship of either economic or financial dependence/interdependence (between member companies or an industrial or financial group, or within a network)" (Kirat and Lung, 1999, 30).

Understanding the nature of U-I linkages is therefore based on the capacity to model institutional proximity after controlling for other forms of proximity and inventor-level characteristics and preferences. Conversely, in order to shed new light on the factors facilitating or hindering U-I collaborations, it is necessary to explore the complementarity or substitutability between institutional proximity and other proximities and/or inventors' characteristics. It is true that for U-I collaborations to happen innovators have to overcome 'institutional' barriers but it is also possible that other forms of proximity (or inventors' characteristics) might 'compensate' for such obstacles. Shared habits and norms tend also to show dynamic reinforcement processes and co-evolution at the local level, compensating for University-Industry differences within the same national institutional framework. In addition, geographical proximity might lead to 'better' U-I ties – "more durable or more likely to emerge from a prolonged search" (D'Este et al., 2013, 542) – or facilitate local cumulative processes whereby existing U-I connections facilitate further links by means of imitation effects and institutional learning. Conversely, the disadvantages associated with initiating partnerships over geographical distance – e.g. uncertainty, information asymmetry, lack of coordination, opportunism (e.g. Mora-Valentin et al., 2004; Veugelers and Cassiman, 2005) might be counterbalanced by the possibility to access newer non-

[3] Note that some authors have recently claimed that the Mertonian distinction between the academic and the non-academic environments may hide differences within them and particularly within the former (Perkmann et al., 2012).

redundant knowledge that would not be available locally. While the economic geography literature has focused on the interactions between U-I linkages and geographical proximity, research in the field of innovation studies has placed more emphasis on the importance of individual-level characteristics, and in particular on the prominent role of star inventors (e.g. Azoulay et al. 2008, Bercovitz and Feldman, 2010, Subramanian et al., 2013)– i.e. individuals with a long track-record of often highly influential patents – who can often act as 'bridges' (Subramanian et al. 2013) between different communities and institutional contexts.

2.2 University-industry linkages in Italy

The case of Italy is particularly well-suited to the study of U-I collaborations. First - notwithstanding the crucial role attributed in principle to U-I collaborations for national and regional innovation performance - Italy lacks a dedicated and coherent public policy strategy in this area, making it possible to analyse collaboration patterns in a relatively neutral policy environment (Geuna and Rossi, 2013). Second, the university system is almost exclusively public and academics/researchers all have the status of civil servants with largely centralised and homogenous recruitment procedures and career/incentives structures. Third, in contrast to this macro-level homogeneity, Italian regions show remarkable differences in international standing and quality of their universities, as well as highly differentiated conditions in terms of institutional and social capital quality.

The nature and determinants of U-I linkages in the Italian context have been explored in a number of studies. By using network analysis in the microelectronics industry, Balconi and Laboranti (2006) point to three main features of Italian U-I collaborations: better scientific performance is associated with stronger ties between industry and university; cooperation relies substantially on face-to-face interaction; cross-border collaborative ties tend to be driven by cognitive and social proximity (see also Abramo et al., 2009; Cesaroni and Piccaluga 2015).

Giuliani at al. (2010) carry out a similar exercise for the wine industry, comparing the case of Italy with that of two other countries, namely Chile and South Africa. The authors find that researchers with better links with industry are young, female and central in their national academic research systems. What makes researchers central in U-I networks is informal power based on personal networks, rather than influence based on formal academic position or expertise (i.e. publications or educational achievements).

The crucial role of academic inventors within networks of inventors is also a main finding of Balconi et al. (2004) who take co-patenting as a proxy of social distance. Academic inventors tend to maintain their 'open' approach even when collaborating within networks of inventors involving proprietary technology, as they exchange more information with more people. In addition academic inventors are more 'central' and better connected than non-academic ones.

The determinants of U-I linkages in Italy have also been explored by looking at project-based collaborations. For example Muscio and Nardone (2012) study the drivers of knowledge transfer from academic departments to firms in the food industry by looking at the dynamics of private funding to university research. They stress the importance of geographical proximity along with the existence of university technology transfer services to facilitate collaboration.

In general, research in this area converges on the important role played by academic inventors in research collaborative networks. Nevertheless, the role of proximity is still ambiguous, particularly with respect to the extent of complementarity versus substitutability among the various forms of proximity in different contexts. Bodas Freitas et al. (2013) explore two different modes of U-I interaction in Italy - namely the institutional and personal modes - and support the prominence of geographical proximity in shaping Italian U-I interactions.

In this growing body of literature a number of relevant aspects of U-I links in Italy still remain underexplored. First, to the best of our knowledge, the present study is the first to take into account different types of proximity at the same time in the study of U-I relationships. Second, studies at the inventor level are still rare in this field. Perkmann et al. (2013) conclude that *"individual discretion seems the main determinant of academic engagement with industry"* (433). Bodas Freitas et al. (2013) find that half of the academics who engage in collaboration with industry use personal contractual arrangements. Therefore, research based on 'institutionalised' forms of U-I linkages (such as joint grants or research consortia) would overlook around 50% of the whole phenomenon. At the same time, in a context such as Italy where the personal mode of U-I interaction still plays a dominant role (Bodas Freitas et al., 2013; Geuna and Rossi, 2013), firms tend to appropriate the results of innovative collaborations with university: when patents are filed, the applicants are very likely to be the former rather than the latter. Therefore, analyses exclusively focused on firms would overlook the significant involvement of academic scientists. Third, existing contributions have focused on U-I collaborations only, while this paper explores a broader sample which includes all possible forms of collaboration - between and within the two communities – making it possible to identify of the specificities of U-I interactions.

3. Empirical strategy

3.1 Data

Patents have been extensively used as a proxy for innovation activities, despite their well-known limitations (e.g. Archibugi, 1992). This paper uses the dataset KITES-PATSTAT on Italian patents developed by Bocconi University, that includes all patents for the pre-crisis period 1978-2007 with information on applicants and inventors (Lissoni et al., 2006). The dataset includes all information on patents (i.e. publication number, title, abstract, priority date, application year, and technological class), their applicants (i.e. name, address, city, country) and inventors (i.e. name, surname, address, city, province, region, and country). In addition, it is possible to identify a sub-sample of 1,297 *academic inventors* (AI) by relying on information from the Italian Ministry of Education. Information includes, for each academic inventor, academic affiliation, career status – i.e. the Italian equivalent for full, associate, and assistant professor – and scientific field of expertise. The AI database is matched with the patent database making it possible to univocally identify all academic inventors and their patents.

3.2 Methodology and unit of analysis

The empirical strategy follows Crescenzi et al. (2016) and models collaborations at the individual (inventor) level, where the units of observation are *inventor pairs.* In order to control for a number of personal characteristics of the individual inventors we are forced to focus our attention on the sub-sample of multi-patent inventors therefore excluding from the analysis all inventors that have patented only once in our sample. In studying what influences collaboration between two inventors, actual pairs are compared with possible (virtual) pairs that form the 'control group' to test the factors that lead to actual collaborations. In other words, the 'virtual' pairs are collaborations that would have been possible given their characteristics but that did not actually occur. For all pairs (actual and virtual) we compute the 'distance' - or proximity - between individuals in the pair along institutional, geographical, organizational and social dimensions. The model controls for individual, institutional and socio-economic factors that might influence the propensity to cooperate over and above the proximities between partners. We also control for the overall size of the inventing team each couple belongs to in order to account for the overall team structure.

Three complementary dependent variables are employed in the analysis: *i.* a dummy variable indicating whether the pair is an actual pair (actually collaborating) or a virtual pair; *ii.* a continuous count of the number of collaborations per pair, proxing the productivity of the actual collaborations once they are established; and iii. a citation-weighted count of the patents generated by the actual collaboration as a proxy for the science-intensity or generality of the innovation output of the established collaborations.[4]

In principle, it is possible to study all possible pairs in the sample, along with the subset of actual inventor pairs. This approach poses two challenges: first, it is hard to think that an inventor active in the 1970s could collaborate with an inventor active at the end of the 2000s; second, the potential number of pairs which can be observed over different decades makes the calculation computationally extremely intensive. We therefore follow a sampling strategy:[5] we first randomly sample 10% of patents, stratified by year, 121 three-digit technology fields and inventor team size; second, we create a set of *possible pairs* (pairs who might have co-invented but did not) and a set of *actual pairs* (pairs who actually co-invented). We end up with an unbalanced panel of 628,509 observations, of which 36,910 are actual pairs.

We build a panel for the years 1987-2007, divided into two ten-year periods, 1987-1996 and 1997-2007. We use the first ten years 1978-1986 to provide information on inventors' patenting activity which is used to control for unobserved heterogeneity in individuals in the period 1987-1996; similarly, we use data of the period 1987-1996 to control for individual heterogeneity during the years 1997-2007.

3.3 The model

The empirical model is specified in Equation 1 below. For inventor pair *ij* in the ten-year period *t,* and technology field *f,* the specification is:

[4] For the second and the third dependent variable the virtual pairs have always a value equal to 0, since they have not co-patented.

[5] See also, for similar strategies, Sorenson et al. (2006), and D'Este et al. (2013).

$$Y_{ijtf} = a + PROXb_{ijtf} + GEOc_{ij} + INVd_{ij} + INSTf_{ij} + TEAMg_{ij} + z_f + k_t + e_{ijtf} \quad (1)$$

where Y is either a dummy for an actual/possible co-inventing pair (DCOINVENT), or the count of a pair's co-invented patents (#COINVENT), or a citation weighted count (CITATIONS) in a given ten year period. The variable DCOINVENT takes value 1 if the pair of inventors has patented together, and value 0 if it has not. Instead, the variable #COINVENT is a continuous variable recording the number of co-invented patents. When looking at simple patent counts as dependent variable, each co-invented patent is counted as 1 independently on the importance and scope of the invention (Tajtenberg 1990). As it is extremely relevant to investigate whether innovations generated by U-I collaboration differ qualitatively from those coming either from a solely business-based team or from a purely academic team, we rely on forward citations of the patents generated by each couple. Forward citations are correlated with both the technological impact (or 'generality') and market and social value of innovation (Tajtenberg 1990; Hall et al., 2005). Patents involving academic partners are more likely to be the outcome of basic research, while patents in which only private companies are involved tend to be more 'applied' in nature. Leaving aside the huge difficulties in distinguishing between basic and applied research (e.g. Stokes 1997; OECD 2002), and taking into consideration the fact that also private companies need to perform basic research (e.g. Rosenberg 1990; Pavitt 1993), university-based patents tend to be broader in terms of underlying scientific and technological knowledge. We therefore employ a measure of forward citations which is meant to capture the basic-science intensity and the influence of each patent on future innovations (Trajtenberg 1990; OECD 2009).

The potential emergence of a difference in the nature of the patents resulting from U-I collaboration with respect to those resulting from other types of collaboration, i.e. within industry or university, can add important qualitative insights in this field, as well as more tailored policy prescriptions. The development of an indicator of forward patent citations has to deal with two operational challenges. First, older patents are – ceteris paribus – automatically more cited than newer ones, thus making it necessary to include a control for the priority date of the patent and year dummies for temporal effects. Second, patent citations tend to differ across technological classes (Hall et al., 2005). Forward citations are therefore normalized looking at the share of citations within each patent's technological class (based on a thirty-sector classification): our dependent variable is the share of forward citations within the technological class of the patent generated by each pair of inventors (2-digit International patent classification IPC). Finally, when looking at this indicator our controls include the type of organization in which inventors work: since virtual pairs do not necessarily share the same patent, this step of the analysis is based on actual pairs only (with no random sampling).

The independent variables are defined as follows:

Proximities (PROX) – The vector PROX includes the key variables of interest – institutional and geographical proximity - and controls for other relevant forms of proximities between the inventors.

> *Institutional Proximity*: a dummy variable taking value 1 if inventors in a pair belong to the same type of institution, i.e. inventors in a pair both work either in a university or in the private sector

(i.e. business firm); the dummy takes value 0 when one of the inventors is based in a company and the other in a university. The latter case identifies U-I linkages. [6]

In order to capture the capability of 'star inventors' to bridge (or not) institutional distance a set of three additional dummy variables is built, taking value 1 if: i. there is at least one star inventor in the pair; ii. there is at least one academic star inventor in the pair ; iii. there is a least one business star inventor in the pair. An inventor is a 'star' – therefore the variable takes a value of 1 - if she invented a number of patents above 75% (third quartile) of the entire distribution of patents.

Geographical Proximity: the inverse of the linear physical distance expressed in kilometers between two inventors measured in logarithm and based on their residential addresses.[7]

We also control for the following proximities:

Organisational Proximity: this dummy variable is a proxy for the likely embeddedness of the inventors' couple into the same organization[8] and takes value 1 if both inventors work in the same company or in the same university, research center, or other types of organization

Social Proximity / Position in co-invention network: a set of dummies is included in the model, taking value 1 if: i. inventors' pair co-invented in the previous period; ii. inventors' pair has worked for the same organization in the previous period; iii. inventors' pair shared a co-inventor in the previous period (i.e. the current collaboration is the closure of a triad).

In addition, in order to single out the role of various proximities and their interactions, a number of other inventor characteristics that might influence collaboration choices are included:

Geographical Factors (GEO) – The vector GEO takes into account the place of residence (i.e. macroregion) of inventors, i.e. whether they live in the North, Center, or South of Italy. The vector also includes a dummy variable that considers whether at least one of the inventors lives in a large city with major universities (i.e. Milan, Rome, Turin, Naples).

Inventor characteristics (INV) – The vector INV takes into account the patenting behavior of each inventor in the previous ten-year period. Two sets of dummy variables are included in the equation and equal 1 when: *i.* the inventor patented in the previous period; *ii.* the inventor patented always alone, always in team, or both ways.

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[6] U-I linkages are identified by the diversity of the type of institution the inventors belong to (affiliation with a private company vs. university), while the applicant (assignee) of the patent can be either the university or the company. Therefore both patents whose applicant/assignee is a university and patents whose applicant/assignee is a company can be identified as U-I linkages to the extent that there are both business inventors and academic inventors in the same patent. What makes it possible to univocally identify academic inventors is the merge of the patent dataset – as discussed in the data section of the paper – with the exhaustive list of all Italian Academics provided by the Italian Ministry of Education.

[7] The distance is calculated on the base of the province of residence of the inventor. Italy is divided into 110 provinces.

[8] Throughout the paper the terms organization refers to a company, a university, a research center, an NGO etc.

Institutional Factors (INST) – The vector INST provides information on the type of organization (firm, university, other) behind the inventor. A set of dummy variables is included in order to identify whether the inventor works in a private business firm, a university or a public research center, or a foundation/NGO/consortium. This information is based on the applicant of the patent.

Team Factors (TEAM) - Since our unit of analysis is the couple two different situations can occur. A co-invented patent can include only the two inventors of the couple, or it can include more than two inventors. In this latter case the inventors in a couple are part of a larger team. A dummy variable that takes into account if the pair is part of a large team has been therefore also added to the model.[9]

Finally, patent technological classes (z) (2-digits) and year dummies (k) are included in the estimates. Appendix 1 reports all the variables included in the model.

3.4 Descriptive statistics

Figure 1 plots the share of co-invented patents on the total over the entire period of analysis, showing how collaborative invention has progressively become the norm among Italian inventors (in line with the general trend worldwide – see Lee and Bozeman 2005; Jones et al. 2008). Figure 2 shows the percentage of inventors: *i.* who have always co-invented with others over their entire career (*team*); *ii.* who have always invented on their own (*solo)*; *iii.* who have both invented in team and on their own (*mix*). The share of inventors always co-inventing rises over time from 60 per cent up to about 70 per cent of the total, whilst that of solo inventors declines from 40 per cent to less than 30 per cent. The proportion of 'mix behavior' inventors remains low and stable over time. Overall, this suggests that inventors' preferences in terms of collaboration choices tend to remain relatively stable over their life-time with team-invention progressively becoming the norm for younger generations

As discussed in the previous paragraph, one of the key strengths of our dataset is the possibility to clearly identify academic inventors.[10] Figure 3 shows the share of co-invented patents on the total by macro-region, confirming the general strength of the Italian northern regional system of innovation, where collaborative linkages and innovation networks are far more entrenched than in the rest of the country, and particularly in the South. This picture is broadly confirmed in Figure 4 – which reports the share of academic patents by macro-region. However, here the weight of the central regions is much more prominent, due to the major role played by the capital region, Lazio, and Rome as location of universities, public and private research institutes, and large (often foreign-owned) science-based firms (Iammarino, 2005).

[9] Note that this variable is not included in the model with the first dependent variable (actual versus virtual pair) since it would predict exactly the actual pairs.

[10] Although 'academic patents' can have multiple inventors from different types of organisations, the definition refers to patents in which there is at least one inventor based in a university.

Figure 1 – Share of co-invented patents on total patents, 1978-2007

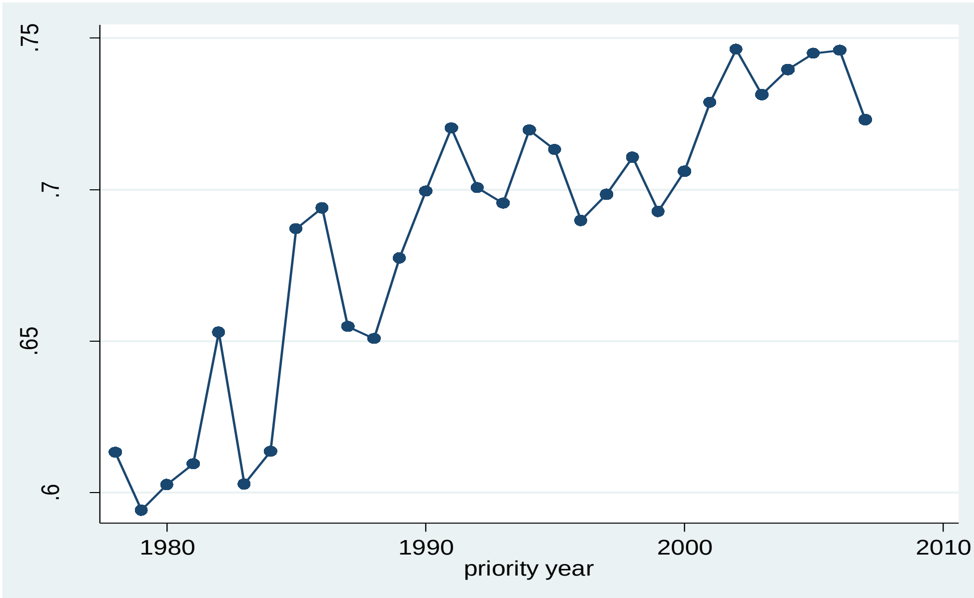


Figure 2 – Shares of inventors patenting alone, in team, or both for every year

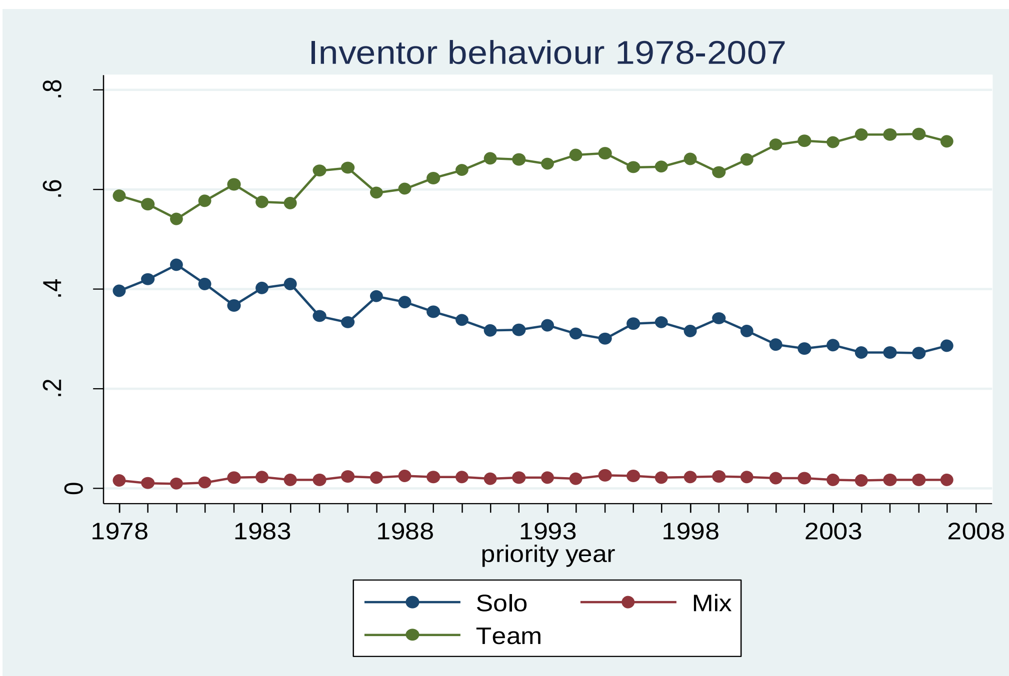


Figure 3 – Share of co-invented patents by macro-regions in 1978-2008.

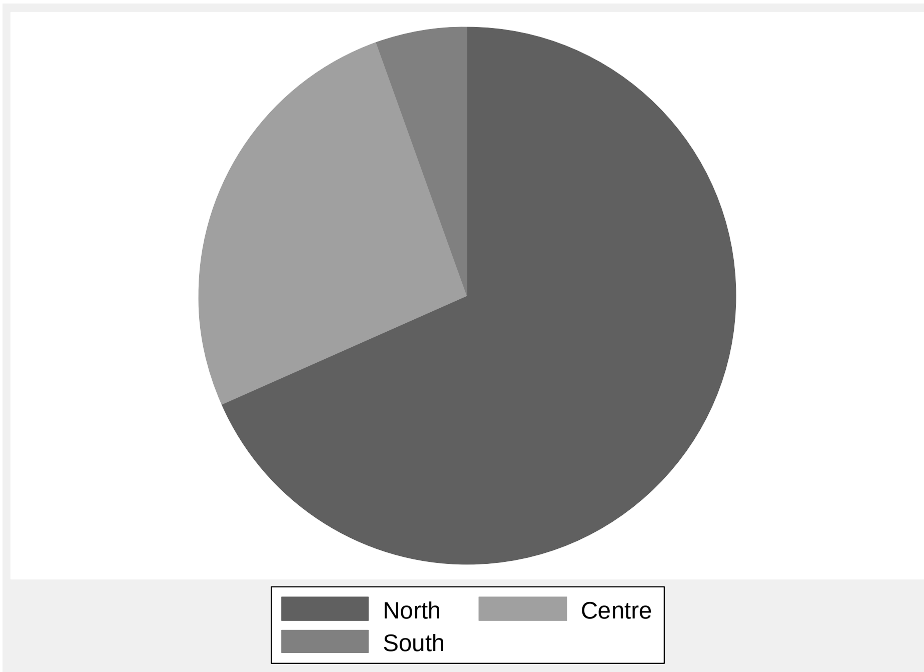
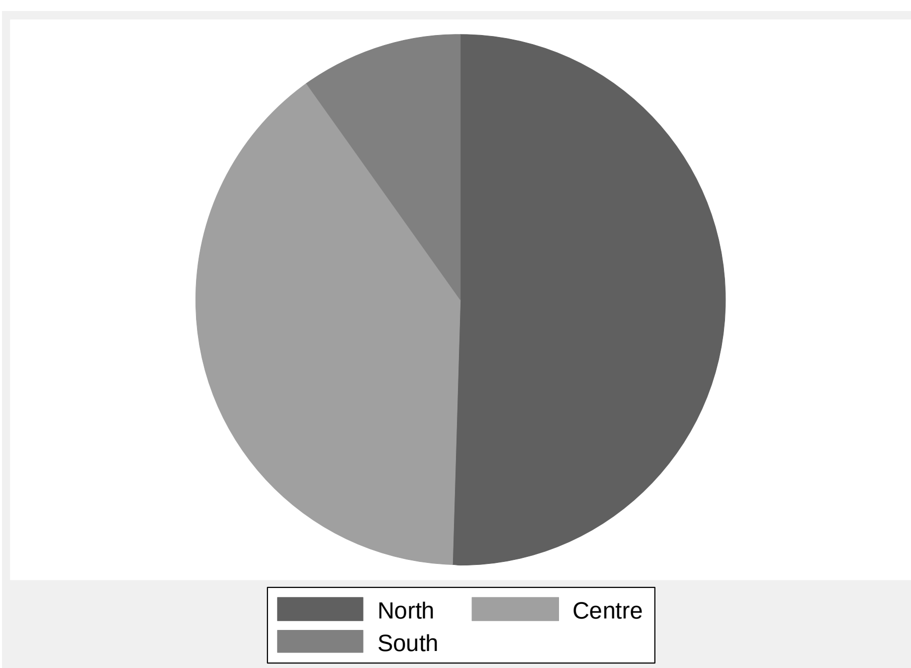


Figure 4 – Share of academic patents by macro-regions in 1978-2008.



The propensity of academic inventors to collaborate is highly heterogeneous across scientific disciplines.[11] In 'basic science' disciplines (e.g. Urology, Neuropsychiatry or Pediatric surgery) patents tend to include only academic inventors. On the contrary, in 'applied' academic disciplines (e.g. Chemistry and Engineering) academics patent more with inventors from the business sector.

When looking at our full sample of 1,335,112 collaboration pairs (with 1,240 actual pairs in total), 74% are collaborations (pairs) between inventors both based in a private firm (*firm-firm collaboration),* 3% are collaborations involving exclusively university partners (*uni-uni collaborations)* and 23% are collaborations between academic and firm-based inventors (*uni-firm collaborations)*. Out of the 1,240 actual pairs, 859 are *firm-firm collaborations,* 42 are *uni-uni collaborations,* and 339 are *uni-firm collaborations.* Among all the pairs, 4.53% include an academic star, of which 1% are actual pairs.

In terms of the job title of the academic inventors, in the whole sample 57.37% are full professors, 25.29% associate professors, and 17.34% assistant professors. By looking at the overall actual pairs, a rise in the share of full and assistant professors clearly emerges, associated to a decline of associate professors. This is also reflected by looking at the actual pairs between an academic inventor and a firm inventor – i.e. U-I linkages – whereas full professors play a greater role in establishing collaborations with the business sector.

4. Empirical results

Types of proximity and types of collaboration

Table 1 includes the key results for the estimation of Equation 1 for the 1987-2007 period. Columns 1 to 3 show the results with respect to the probability of collaboration (DCOINVENT) and are based on probit estimates;[12] column 4 reports the findings for the count of each pair's co-invented patents (#COINVENT) on the basis of negative binomial estimates;[13] columns 5 and 6 present results for the citation-weighted patent count (CITATIONS), using negative binomial and Tobit estimates respectively.[14]

[11] Note that these are different from the patent technology classes: academic positions in Italy are classified according to a pre-defined set of 'scientific disciplines' that identify the macro area of expertise of the post-holder for both teaching and research purposes.

[12] All estimates presented have been computed also by using OLS yielding similar results (see Appendix 2). Note also that introducing the control variables one group at a time does not affect the results. We therefore report only the results with all controls, while the main regressors are included in a stepwise way.

[13] Since the dependent variable in this case is a count variable, it would be possible to rely on either Poisson or negative binomial estimates. After tested the goodness for both, we opted for the negative binomial model with robust standard errors. Instead, we ruled out zero inflated types of modes since in principle all inventors can form a couple, i.e. decide to collaborate. Also in the case of the negative binomial estimates results are robust to using an OLS specification with robust standard errors.

[14] Note that in this case the number of observations drops considerably due to the presence of several missing among the citations.

Table 1 – Results - Dependent variables: Dummy variable: co-invented patent dummy (columns 1-3); Count variable: #co-invented patents per inventor pair (column 4); Share of citations within the same technology class (columns 5-6)

	(1) DCOINVENT	(2) DCOINVENT	(3) DCOINVENT	(4) #COINVENT	(5) CITATIONS	(6) CITATIONS
institutional proximity	0.911***		0.744***	0.994***	-0.0837***	-0.00000707***
	(0.0258)		(0.0241)	(0.0414)	(0.0203)	(0.00000169)
geographical proximity		2.347***	2.215***	2.517***	0.155***	0.0000104***
		(0.0368)	(0.0376)	(0.0747)	(0.0243)	(0.00000207)
inventors work in the same organization	3.542***	3.314***	3.315***	3.411***	-0.0980***	-0.00000864***
	(0.0131)	(0.0132)	(0.0134)	(0.0312)	(0.0179)	(0.00000156)
inventor pair has co-invented previously	1.656***	1.665***	1.655***	1.111***	-0.0425***	-0.00000351***
	(0.0606)	(0.0591)	(0.0590)	(0.0540)	(0.0135)	(0.00000117)
inventor pair has worked in the same organization previously	-1.119***	-1.054***	-1.066***	-0.243***		
	(0.0698)	(0.0695)	(0.0690)	(0.0740)		
inventors have patented with a third inventor previously	-0.0424	-0.0818	-0.0791	-0.120	-0.0609**	-0.00000688***
	(0.0553)	(0.0539)	(0.0545)	(0.0827)	(0.0239)	(0.00000214)
at least one inventor lives in a Central region	-0.488***	-0.533***	-0.505***	-0.698***	-0.0292	-0.00000287
	(0.0608)	(0.0625)	(0.0628)	(0.115)	(0.0203)	(0.00000180)
at least one inventor lives in a Southern region	-0.727***	-0.584***	-0.602***	-0.966***	-0.0173	-0.000000742
	(0.0593)	(0.0607)	(0.0610)	(0.113)	(0.0188)	(0.00000168)
at least one inventor lives in a large city	0.0720***	-0.177***	-0.175***	-0.166***	-0.0330***	-0.00000309***
	(0.0116)	(0.0131)	(0.0132)	(0.0241)	(0.00793)	(0.000000683)
inventor characteristics	included	included	included	included	included	included
Institutional factors	included	included	included	included	included	included
team factors				0.587***	0.110***	0.0000109***
				(0.00860)	(0.00191)	(0.000000220)
technological class of the patent	included	included	included	included	included	included
year dummy	included	included	included	included	included	included
priority year					-0.00410***	-0.000000334***
					(0.00147)	(0.000000126)
Constant	-2.994***	3.695***	2.612***	2.592***	-9.487***	0.0000605***
	(0.0712)	(0.114)	(0.121)	(0.246)	(0.0779)	(0.00000650)
lnalpha						
Constant				0.602***	-12.36***	
				(0.0202)	(0.00678)	
sigma						
Constant						0.0000450***
						(0.000000724)
Observations	586367	586367	586367	586436	28818	28818

Note: * p<0.10; ** p<0.05; *** p<0.01

Column 1 shows the baseline results for the key variable of interest: institutional proximity. The positive and highly significant coefficient suggests that institutional proximity – i.e. belonging to the same type of institution, either academia or business – facilitates collaboration among inventors. This implies that – ceteris paribus – University-Industry collaborations are more 'difficult' and less likely to occur than the other forms of collaboration, due to different sets of incentives, norms and practices regulating activities and acting as barriers to collaborative behavior. For instance, private firms might find it difficult to anticipate the potential commercial application of academic research, with associated high search costs for the identification of the best possible partner(s) in a new project. Symmetrically, academics may find it easier to collaborate with other academics whose 'quality' is clearly assessable on the basis of common indicators (e.g. publications or academic reputation).

All other coefficients in the model behave as expected: organizational proximity (i.e. being affiliated with the same university or the same company) facilitates collaboration. The position in the social network of inventors is also important for collaboration: having co-invented in the previous period has a positive association with current collaborations, while having worked for the same organization seems – ceteris paribus - to discourage inventive cooperation. If inventors are part of the same organization and do not collaborate it is very unlikely that they will collaborate on future occasions once they leave this organisation. Having had a co-inventor in common in the past (i.e. closing a triad with a new collaboration) does not affect the probability of collaboration: in other words, the degrees of separation between two inventors in the co-invention network do not exert a statistically significant influence on new collaborations. The geographical macro-regional dummies confirm the well-known dualism of the Italian innovation system, with the South of Italy, and to a lesser extent the Centre, suffering from less collaborations among inventors than the North (reference category for the dummy variables). The location of inventors in major urban areas increases the probability of collaboration.

In column 2 the focus of the analysis shifts to the role of geographical proximity between inventors: the positive and highly significant coefficient suggests that – ceteris paribus – geographical proximity facilitates innovative collaboration, in line with the existing evidence from the geography of innovation literature. Column 3 reports results when both institutional and geographical proximity are included together in the model, with no relevant changes in their coefficients' size and significance: both proximities play a relevant role in shaping collaborations.

Column 4 looks at the 'productivity' of inventive partnerships, counting the number of patents produced by actual collaborations. Even after introducing an additional control for the overall structure of the patenting team, the same factors that facilitate collaborations also influence productivity. The lack of institutional proximity that characterizes U-I linkages reduces the number of patents produced by these collaborations, once they are formed.

Therefore, University-Industry collaborations are both more difficult to establish and quantitatively less productive than other forms of cooperation among inventors. However, columns 5 and 6 suggest that, when it comes to the forward-citations attracted by the patents generated by inventors' collaborations, institutional proximity has a negative influence. Collaborations involving exclusively either academics or firm-based inventors attract less forward citations than University-Industry collaborations. Therefore, once established, the latter links tend to produce qualitatively different patents that, because of science-intensity and degree of generality tend to find application in a larger number of subsequent innovations. Geographical proximity still exerts a positive influence on citations suggesting that face-to-face contacts are also supportive of patents' capacity to influence subsequent innovative projects. However, belonging to the same organization has the opposite effect, as well as (although with at a lower significance level) having collaborated on a previous occasion: these findings might be interpreted in the light of a higher propensity of collaborations within-organization and/or repeated over time to bring about cognitive lock-in, therefore having a weaker impact on future discoveries.

How proximities complement or replace each other

In order to explore the degree of complementarity (or substitutability) among the various forms of proximity here considered, in Table 2 a number of interaction terms are included into the model to estimate the probability of collaboration. In columns 1 and 2 we explore the interaction between institutional proximity and geographical space, while in columns 3 and 4 we look at the interaction between the former and various measures of inventors' quality and reputation as potential 'bridges' between university and industry.

The interaction term between institutional and geographical proximity shows a negative and highly significant coefficient, indicating that geographical proximity works as a substitute for institutional proximity. In the absence of institutional proximity (as in University-Industry linkages) physical propinquity might be able to spur innovative collaboration. The possibility to interact with potential collaborators within the same locality makes it easier for both universities and firms to 'signal' the quality and relevance of their research, facilitating the matching process beyond institutional barriers. In column 2 we also consider micro-geographic proximity – i.e. the inventors are located in the same major city – which per se does not influence the probability of collaboration, even if it does interact negatively with institutional proximity. This may indicate that it is easier to bridge the institutional gap in large urban agglomerations, where the higher diversity of cognitive and skill bases makes it easier to identify the 'right' complementarities, irrespective of the affiliation of the individual inventors.

Table 2 – Results - Dependent variable: Dummy variable: co-invented patent dummy

	(1) DCOINVENT	(2) DCOINVENT	(3) DCOINVENT	(4) DCOINVENT
institutional proximity	-0.143	0.846***	0.879***	0.817***
	(0.322)	(0.0317)	(0.0277)	(0.0278)
geographical proximity	2.558***	2.218***	2.220***	2.221***
	(0.130)	(0.0376)	(0.0381)	(0.0376)
institutional prox. * geographical	-0.370***			
	(0.134)			
pair with at least an academic star			0.449***	
			(0.0549)	
institutional proximity with academic star			-2.933***	
			(0.123)	
pair with at least a business star				0.151***
				(0.0530)
institutional proximity with business star				-0.284***
				(0.0550)
at least one inventor lives in a large city	-0.175***	0.0481	-0.177***	-0.174***
	(0.0132)	(0.0457)	(0.0134)	(0.0132)
institutional proximity in large city		-0.241***		
		(0.0469)		
inventors work in the same organization	3.318***	3.317***	3.334***	3.321***
	(0.0134)	(0.0134)	(0.0135)	(0.0134)
same controls as in Table 1	included	included	included	included
Observations	586367	586367	586367	586367

Note: * p<0.10; ** p<0.05; *** p<0.01

Overall this evidence seems to support the importance of geographical proximity for the formation of U-I collaborations. However, in line with some recent empirical literature (e.g. D'Este et al., 2013), the second set of interaction terms suggests that other factors might facilitate the identification of the relevant collaborators: in particular, the reputation and experience of the individual inventors. Column 3 shows that the presence of an academic 'star' (i.e. an academic inventor with a substantial patenting track-record) facilitates collaboration in general, but it can also compensate for the lack of institutional proximity (negative and significant coefficient of the interaction term). Column 4 shows symmetric results for ‘business star inventors’: the latter have a direct positive effect on the probability of collaboration, and a substitution effect with institutional proximity. Star inventors – thanks to their reputation and patenting history – are easier to trust for counterparts belonging to different communities (business world vs. academia) and are also more effective in signaling the nature and commercial applicability of their knowledge/research/innovative activities, facilitating matching. This is true for both academic and business stars, suggesting that ultimately what matters for University-Industry collaboration is the possibility to efficiently deal with information asymmetries and uncertainty at both ends of the partnership. Geographical proximity is only one possible means to address this information problem in collaborators’ matching. Scientists with the capability to translate their research into patentable ideas – signaling relevance and applicability of their innovative activities – can pursue an equally important function.

5. Conclusions

This paper has explored the factors that characterize collaborations between inventors. Specifically, the paper has focused on the lack of ‘institutional’ proximity as a key barrier that University-Industry collaborations have to overcome, exploring its interaction with geographical proximity and other relevant collaboration drivers. The results suggest that U-I collaborations are less likely to happen when compared to other cooperative links: institutional differences between business and academia hinder the signaling process necessary for an effective search and match of potential collaborators. However, once U-I collaborations are established they tend to generate patents of more general applicability in technological terms, i.e. more likely to form the basis for subsequent technological applications. Geographical proximity plays an important role in facilitating all forms of collaboration. At the same time, it works as a possible substitute for institutional proximity, facilitating U-I collaborations. The reputation and patenting curricula of the inventors on both sides of the partnership is also a relevant ‘bridge’ between universities and industries.

The paper is innovative in a number of respects. The analysis has looked simultaneously at all possible types of inventive collaborations, identifying the specificities of U-I relationships against a broad relational spectrum. Our approach has made it possible to shed new light on the rationale for the special attention devoted to U-I links in both scholarly and policy work.

The broader perspective offered by this approach is not free from limitations. First, by looking at patents we only observe collaborations that: a) are successful (i.e. lead to an output); b) result in a patentable output (while successful collaborations may well lead to non-patentable forms of innovation). Second, our analysis cannot distinguish between different possible channels of collaboration (informal collaborations, collaborative research grants and projects, joint-ventures, consultancies, etc.). Third, the lack of an exogenous variation in the proximity relations among inventors makes it difficult to interpret our results in terms of causality.

Having acknowledged these limitations, our results offer relevant material for reflection on the best targets for innovation policies. As discussed in the introduction, governments around the world are devoting an increasing share of resources to the support of U-I links. Very often these policies have been implemented in the context of actions aimed at reinforcing the innovative performance of clusters, or have resulted in the development of physical infrastructure (or subsidies for office/laboratory space) in order to foster spatial proximity between universities and private firms. Our results confirm the 'special' nature of U-I collaborations: they do face more difficulties/barriers than other collaborations, providing a rationale for policies that try to minimize such barriers.

However, our results also suggest a number of relevant caveats. First, forms of support for U-I linkages are only justified when trying to foster more 'general purpose' innovations. In innovation systems where imitation and absorption are the norm (e.g. in less advanced countries and regions) this type of inventions might not necessarily be realistic targets for local innovative actors. Second, geographical proximity is not the only (and not necessarily the most cost-effective) way to facilitate U-I collaborations. While spatial proximity certainly facilitates collaborations, other mechanisms might produce equally beneficial effects with less ambiguous side-effects. Particularly in less developed regions, improvements in the quality of local universities and the simultaneous reinforcement of technological capabilities of private firms are key to foster innovation linkages and networks in a systemic fashion. Third, policy makers always have the option to focus their attention on the framework conditions that facilitate all possible forms of collaborations, allowing individual agents to choose the most suitable business or university partners depending on their particular technological needs and on the conditions of their markets of reference.

Appendix 1 – List of variables

Dependent variables	
	• DCOINVENT: Dummy variable - co-invented patent dummy • #COINVENT: Count variable - #co-invented patents per inventor pair; • CITATIONS: Share of citations within the same technology class (2-digit International patent classification IPC);
Proximities	
Institutional and geographical	• Institutional proximity (dummy variable): inventor pairs share the same type of organization (both inventors from universities or from the business = 1; one inventor from university and one from business = 0); • Geographical proximity (continuous variable): inverse of distance;
Organisational and social proximities (controls)	• inventor pair work in the same organization (dummy variable); • inventor pair has co-invented previously (dummy variable); • inventor pair has worked in the same organization previously (dummy variable); • inventor pairs has co-invented with the same third inventor previously; • # of teams the inventor is part of (continuous variable);
Individual control variables	
Geographical factors	• Location of the inventor, macro region: i.e. north, centre, south (categorical variable (1=at least one inventor lives in the North; 2= at least one inventor lives in the Center; 3= at least one inventor lives in the South); • City (dummy variable): at least one of the inventor resides in a large city where there are major universities (Milan, Rome, Turin, Naples);
Inventor characteristics	• Inventors have always patented alone previously (dummy variable); • Inventors have always patented in team previously (dummy variable); • Inventors have patented both alone and in team previously (dummy variable); • Star (dummy variable): inventor with a number of patents over 75%; • Business star (dummy variable): business inventor with a number of patents over 75%; • Academic star (dummy variable): academic inventor with a number of patents over 75%;
Institutional factors	• Applicant is private (dummy variable); • Applicant is a public (dummy variable); • Applicant is no-profit (dummy variable);
Team factors	• A dummy variable that takes into account if the pair is part of a large team
Other controls	• Technological classes (2-digit International patent classification IPC) • Year dummies;

Appendix 2

Robustness checks: same estimates as for Table 1 with OLS

	(1) DCOINVENT	(2) DCOINVENT	(3) DCOINVENT	(4) #COINVENT	(5) CITATIONS
institutional proximity	0.0155***		0.0125***	0.0491***	-0.00000402***
	(0.000395)		(0.000383)	(0.00213)	(0.00000118)
geographical proximity		0.121***	0.118***	0.304***	0.00000985***
		(0.00199)	(0.00198)	(0.0136)	(0.00000126)
inventors work in the same organization	0.735***	0.717***	0.716***	1.737***	-0.00000620***
	(0.00226)	(0.00234)	(0.00234)	(0.0238)	(0.00000109)
inventor pair has co-invented previously	0.249***	0.246***	0.245***	3.626***	-0.00000231***
	(0.00418)	(0.00414)	(0.00413)	(0.104)	(0.000000663)
inventor pair has worked in the same organization previously	-0.201***	-0.197***	-0.197***	0.416*	
	(0.0110)	(0.0109)	(0.0109)	(0.218)	
inventors have patented with a third inventor previously	-0.0321***	-0.0331***	-0.0332***	-3.662***	-0.00000309***
	(0.0101)	(0.00999)	(0.00996)	(0.192)	(0.00000117)
at least one inventor lives in a Central region	-0.0495***	-0.0498***	-0.0495***	-0.333***	-0.000000790
	(0.00687)	(0.00675)	(0.00674)	(0.0623)	(0.00000109)
at least one inventor lives in a Southern region	-0.0614***	-0.0582***	-0.0591***	-0.391***	-0.000000433
	(0.00685)	(0.00673)	(0.00672)	(0.0618)	(0.00000100)
at least one inventor lives in a large city	0.00199***	-0.00548***	-0.00549***	-0.0202***	-0.00000204***
	(0.000344)	(0.000342)	(0.000342)	(0.00259)	(0.000000415)
inventors are part of a larger team				0.686***	0.00000634***
				(0.00732)	(0.000000123)
priority year					-0.000000277***
					(7.88e-08)
Constant	0.323***	0.652***	0.633***	0.343	0.0000779***
	(0.00852)	(0.0125)	(0.0124)	(0.888)	(0.00000427)
Observations	586436	586436	586436	586436	28818

Note: * p<0.10; ** p<0.05; *** p<0.01

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