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A bibliometric portrait of the evolution, scientific roots and influence of the literature on university–industry links

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Abstract The study of university–industry (U–I) relations has been the focus of growing interest in the literature. However, to date, a quantitative overview of the existing literature in this field has yet to be accomplished. This study intends to fill this gap through the use of bibliometric techniques. By using three different yet interrelated databases—a database containing the articles published on U–I links, which encompass 534 articles published between 1986 and 2011; a 'roots' database, which encompasses over 20,000 references to the articles published on U–I relations; and a 'influences' database which includes more than 15,000 studies that cited the articles published on U–I relations—we obtained the following results: (1) 'Academic spin offs', 'Scientific and technological policies' and (to a greater extent) 'Knowledge Transfer Channels' are topics in decline; (2) 'Characteristics of universities, firms and scientists', along with 'Regional spillovers', show remarkable growth, and 'Measures and indicators' can be considered an emergent topic; (3) clear tendency towards 'empirical' works, although 'appreciative and empirical' papers constitute the bulk of this literature; (4) the multidisciplinary nature of the intellectual roots of the U–I literature—an interesting blending of neoclassical economics (focused on licensing, knowledge transfer and high-tech entrepreneurship) and heterodox approaches (mainly related to systems of innovation) is observed in terms of intellectual roots; (5) the influence of the U–I literature is largely concentrated on the industrialized world and on the research area of innovation and technology (i.e., some 'scientific endogamy' is observed).

Keywords University–industry links · Entrepreneurial universities · Technology transfer · University spin offs · Bibliometrics

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Introduction

The study of university–industry (U–I) relationships has been the focus of growing interest in the literature (Bekkers and Freitas 2008; Gulbrandsen et al. 2011), and the contribution of universities to regional development through the production and transfer of knowledge is widely acknowledged (Salter and Martin 2001; Coccia 2004; Mueller 2006; Breznitz et al. 2008; Giuliani and Arza 2009; Abramo et al. 2012). In fact, the creation of useful knowledge and transfer of new methodologies to industry, in the context of an interactive network, can open up new opportunities, potentially leading to great technological advancements, and lead to the need to train qualified personnel, with a greater ability to solve problems, as well as to increased productivity on a regional or national level.

In this context, the need to analyze the consequences of political decisions regarding Research and Development (R&D) becomes vital, in order to encourage formal and informal contacts between Universities and Industry (U–I) and to understand how these relationships are established. Several issues have merited the attention of researchers and political authorities (at national and regional levels), namely: the channels used; the role played by agents and intermediaries; motivations for establishing U–I relationships; practical impacts of the scientific and technological policies adopted on the regional/national levels; relevance of academic spin offs for regional innovation systems; barriers to the knowledge transfer process.

Even though there are several qualitative studies on the scientific evolution of U–I relationships (Rothaermel et al. 2007), to our knowledge, a more quantitative approach based on bibliometric techniques has yet to be undertaken. Bibliometrics, combined with author citation analysis techniques, serves to identify the academic groups that are formally related within specific research areas (Park and Leydesdorff 2009), which may contribute to the formation of what is often called a *small world* (Fleming et al. 2004; Goyal et al. 2006). Moreover, it provides insights into the processes of information exchange between authors and the origins of ideas, thus enabling the construction of a *science map* (Small 2009; Vera and Schupp 2006) as well as the identification of emerging patterns in a particular field of research (Teixeira 2011).

Therefore, the aim of this article is to provide a quantitative perspective of the cooperative relations between firms/industry and universities, describing the scientific roots of this field, commonly known as invisible colleges, through the use of bibliometric techniques. The study of invisible colleges—as defined by Zuccala (2006)—in U–I relationships, associated with the use of bibliometric techniques to analyze citations, is documented in the literature, such as in the work of Leydesdorff and Meyer (2007) or Fagerberg and Verspagen (2009). However, these studies apply bibliometrics to a limited number of articles on U–I relationships (Leydesdorff and Meyer 2007) or analyze more generic studies on innovation, without explicitly identifying the role of the universities and/or firms (e.g., Silva and Teixeira 2008; Fagerberg and Verspagen 2009).

The main objectives of this study which focuses on the literature regarding U–I relations are threefold: to analyze the evolution of the literature by themes/topics; to identify its origins/roots; and to assess the extent of its influence on this field of research.

To achieve these objectives, we performed a detailed analysis of all the (534) articles published between 1986 and 2011 in academic journals in the area of the Social and Human Sciences which discuss U–I relations, based on the bibliographic database SciVerse Scopus. From these 534 articles, we constructed a 'roots database', comprising 20,423 cited references (i.e., the references made by the articles published on U–I), which allowed us to identify the intellectual roots of the field. Additionally, we constructed an 'influence

database', which encompasses 15,682 studies citing the articles published on U–I, which served to gauge the scope of influence of the U–I literature.

The article is organized as follows. In the next section, a 'qualitative' review of the relevant literature on U–I relationships is performed, attempting to identify the main sub-topics (Sect. 2). Next, Sect. 3 details the methodological considerations underlying the study. The results are discussed in Sect. 4 and, finally, the main points of the study are summarized in the conclusions (Sect. 5).

University–industry relations: main themes of research

There is a widespread belief among researchers and the general public that the direct involvement of science ('Universities') with the world of business ('Industry') has been increasing in recent years, at the same time as policies aimed at fostering knowledge transfer networks have also been implemented (Giuliani and Arza 2009). According to Bercovitz and Feldman (2006), this closer collaboration between universities and firms is related to factors such as the development of new technological platforms, namely from the computational, molecular, biological and material sciences; the growing scientific and technological content of industrial production; the need for new sources of academic research funding, dictated by budget constraints; and the importance of the returns of budget policies aimed at stimulating collaboration between universities and firms.

A number of studies analyze the relationship between U and I from various perspectives, using different agents and spatial, sectoral or disciplinary scopes as their reference. The results, however, have led to a range of findings regarding the importance of the output produced by universities and their patterns of interactions, suggesting the existence of a complex pattern of relationships between U and I, on which there is still scope for examination (Agrawal 2001; Schartinger et al. 2002; Bekkers and Freitas 2008; Gulbrandsen et al. 2011).

Agrawal (2001) proposes a division of the studies on U–I relationships into four categories: (1) the characteristics of the firms, which includes studies related to the business, internal organization, allocation of resources and partnerships; (2) the characteristics of the universities included in analyses, which focus on issues like strategy licensing, incentives to patent and policies aimed at intellectual property; (3) geography in terms of the location of *spillovers*, which includes the spatial relationship between the firms and universities, and (4) the knowledge transfer channels, which take into consideration aspects pertaining to the importance of the various means of interaction between U and I, such as publications, patents, consultancy and informal contacts.

More recently, Bekkers and Freitas (2008) analyzed the literature on U–I relations and organized the studies according to certain aspects associated with technology transfer channels; more specifically, they analyzed which are most frequent, in what type of sectors and scientific disciplines, and on what does the intensity of their use by universities and firms depend.

Studies centred on the *characteristics of the scientists* focus on their influence on the knowledge transfer process between U and I (Edler et al. 2011). These studies document some consistencies: researchers with more experience in collaboration and with a greater number of patents reveal more intense interaction (Lee 1996; Zucker and Darby 1996); the intent to collaborate increases with the associated benefits (career progression, monetary return, acknowledgement in the academic world), and researchers are more likely to collaborate if they can take ownership of the earnings from the invention (Bains 2005; Lam

2005); the experience and professional trajectory of business scientists to universities leads to an increase in scientific and technological human capital, which translates into improved performance, productivity and inventiveness (Lubango and Pouris 2007; Crowe and Goldberg 2009).

Knowledge transfer is also viewed from the perspective of the organizational *characteristics of firms*, which investigates the influence of certain aspects (like strategy, size of the business, volume of investment in R&D, absorption ability, etc.) on the knowledge transfer process between U and I and the choice of channels used (e.g., Cohen et al. 2002; Fontana et al. 2006; Fabrizio 2009; Filatotchev et al. 2011); in which fields (e.g., Zucker et al. 2002; Balconi and Laboranti 2006), and in which activity sectors (e.g., Salter and Martin 2001; Cohen et al. 2002; Marsili and Verspagen 2002; Schartinger et al. 2002; Martinelli et al. 2008; Giuliani and Arza 2009) are U–I relationships most evident. Some studies taking the business perspective state that: dimension and activity influence the type of interactions with universities (Santoro and Chakrabarti 2002); firms with a high investment in R&D are more likely to interact with universities (Fontana et al. 2006); the U–I relationships with greater potential for knowledge transfer are those built on knowledge-based firms or on universities with high scientific quality—more specifically, firms in sectors connected to biotechnology, chemistry, pharmacy and information technologies seem more open to formal and informal collaborations with universities (Meyer-Kramer and Schmoch 1998) and, in the majority of sectors, needs are centred on the fields of Physics, Computer Science, Mathematical Science (Cohen et al. 2002); in technology-based firms, there is usually a two-way relationship (U–I and I–U) with the university (Meyer-Kramer and Schmoch 1998; Pinheiro and Teixeira 2010).

In the studies that mainly examine the *characteristics of the universities* (e.g., Lee 1996; Etzkowitz 1998; Colyvas et al. 2002; Hemmert et al. 2008; Krücken et al. 2009; Koschatzky and Stahlecker 2010), the key focus is on motivations and factors which lead to the creation of U–I relationships. These studies analyze the incentive for universities to disseminate innovations (Krücken et al. 2009; Wu 2009); the importance of the historical factor in U–I relationships (Hemmert et al. 2008), and the enterprising nature of universities (Rothaermel et al. 2007; van Looy et al. 2011). On the whole, these studies conclude that university departments with a stronger focus on applied research and technological development interact more with industry (Lee 1996), and the same applies to universities with substantial private funding (O'Shea et al. 2005).

With regard to *knowledge transfer channels*, some authors conclude that coded knowledge, like publications (Cohen et al. 2002), patents (Narin et al. 1997; Pugatch and Chu 2011) and formal collaboration (Meyer-Kramer and Schmoch 1998; Swann 2002; Monjon and Waelbroeck 2003), are the most important channels. Hiring researchers seems to be an effective knowledge transfer channel, particularly in the areas of chemistry and biotechnology (Zucker et al. 2002; Gübeli and Doloreux 2005). Informal contacts are also often present in interactions between U and I (Cohen et al. 2002). Still within this scope, Cohen et al. (2002) applied a questionnaire (Carnegie Mellon Survey) to assess the influence of public research in the industrial sector in the United States. They concluded that public research is vital for a small number of firms and important for the industrial sector as a whole, where the knowledge transfer channels of choice include publications, reports and public conferences, but informal contacts and consultancy are also standard. Swann (2002), based on a questionnaire targeting firms in England (*Community Innovation Survey* CIS), concluded that firms are more adept at formal collaboration when they innovate in the processes, in a *catch up* situation for an existing level of technology, more

so than when they innovate in products. Also using the CIS but aimed at French firms, Monjon and Waelbroeck (2003) arrived at similar results.

In all sectors, universities and industry/firms use a variety of channels to establish relationships contingent on current objectives, even though some tendencies in the way certain interactions take place can be identified: industries with a strong investment in R&D tend to go for collaborative research, whereas service firms lean towards personal mobility and training (Schartinger et al. 2002). Some studies analyze the way in which knowledge flows between U and I according to scientific fields (e.g., Meyer-Kramer and Schmoch 1998; Zucker et al. 2002; Balconi and Laboranti 2006) and conclude that there is a greater interaction between U and I in the areas of the Natural Sciences, Technical Sciences, Medicine and Social and Economic Sciences, where the main channels used for interaction differ according to the scope of the field (Schartinger et al. 2002; Martinelli et al. 2008).

There are also studies that analyze the creation of new firms (*Spin offs*). In this group, the studies can be divided into two sub-sets (Rothaermel et al. 2007). The first set comprises studies centred on the factors that inhibit the creation and development of spin-offs, like problems related to cultural differences (e.g., Kinsella and McBrierty 1997) or inadequate funding and support structures (e.g., Pazos et al. 2010). The other sub-set focuses on success factors which instigate the creation of spin-offs (Shane and Stuart 2002; Di Gregorio and Shane 2003; Grandi and Grimaldi 2003; Lockett et al. 2003; Johansson et al. 2005; Powers and McDougall 2005; Fini et al. 2011), namely the degree and quantity of resources dedicated to university enterprise and the quantity of resources dedicated to technology transfer offices (TTOs) (O'Shea et al. 2005).

Studies based on the importance and function of intermediary agents (*Technology Transfer Offices* TTOs) in U–I relations in the technology transfer process (e.g., Colyvas et al. 2002; Siegel et al. 2003; Wright et al. 2008; Yusuf 2008; Lee et al. 2010) highlight the importance of intermediation as a factor in the generation of U–I relationships, as well as aspects pertaining to the productivity and mode of operation of TTOs.

Analyses centred on the importance of *location and regional spillovers* for U–I relations also seem to have considerable importance in the literature. The focus is on issues of geographical proximity between universities and firms and, therefore, the majority of studies underline this as an important factor in the creation of relationships (e.g., Lindelöf and Löfsten 2003, 2004; Owen-Smith et al. 2002; Broström et al. 2009). Nevertheless, there are sectors—like biotechnology—where a majority of relationships is not essentially determined by location (Audretsch and Stephan 1996).

Research discussing the implications of *scientific and technological policies* in the national, regional or sectorial innovation system (e.g., Narin et al. 1997; Cantner and Graf 2006; Olds 2007; Xiwei and Xiangdong 2007; Link et al. 2008; Decter 2009; Klincewicz and Miyazaki 2011) mention that the dynamics of the relationships within the innovation system evolve around central competencies of the local innovation system: new innovators are generally located near the core of the network and these relationships are centred on the cooperation and mobility of scientists (Narin et al. 1997; Cantner and Graf 2006).

On the other hand, they mention the need to redirect policies towards the requirements of national innovation systems, specifically of intermediaries in the knowledge transfer process, in order to foster the entrepreneurial and commercial spirit of universities and the absorption ability of firms (Olds 2007; Xiwei and Xiangdong 2007).

Measuring the collaboration between U and I has also been a topic of considerable interest for researchers. In particular, these studies examine the results of the collaboration and the frequency, intensity and efficiency of technology transference by universities (e.g.,

Tijssen 2006; Anderson et al. 2007; Ramos-Vielba et al. 2009; Todorovic et al. 2011). It is therefore found that some collaborations are difficult to detect and differentiate, but firms regard universities as a source of innovation (Ramos-Vielba et al. 2009), since they are gradually becoming more enterprising: the intensity of joint scientific research and publications seems to be growing (Tijssen 2006), given that universities which demonstrate greater efficiency in knowledge transfer are usually considered the top universities in a region/country (Anderson et al. 2007).

Finally, there is a residual group of studies ('*Others*') which, while not clearly integrated in the aforementioned sub-topics, include reviews of the literature (e.g., Wright et al. 2004; Plewa and Quester 2007), analyses of the barriers to U–I relationships (e.g., Lhuillery and Pfister 2009) or scientometric/bibliometric analyses (Park and Leydesdorff 2009; Abramo et al. 2009, 2012).

Despite the myriad of interesting studies on U–I relations, to the best of our knowledge, a quantitative/bibliometric analysis of their temporal evolution by sub-topics and methodologies (formal, empirical, appreciative) has yet to be performed. Similarly, little attention has been paid to the issue of the scientific roots of this area and their respective scientific influence. These aspects are empirically analyzed in Sect. 4. The next section details the methodological aspects of the present study.

Methodological considerations

University–industry relations emerged in the last 30 years as a separate field of research (Gulbrandsen et al. 2011). Thus, a comprehensive analysis of this field of research is likely to prove a useful endeavour.

In the present study, all the articles published in academic journals in the field of the Social and Human Sciences on the topic of 'U–I relations' were gathered and analyzed. Based on the SciVerse Scopus bibliographical database and guided by the existing studies in the area, we used a varied combination of search keywords: "university and industry" and "linkages"; "university and industry" and "technology transfer"; "university and industry" and "science park*"; "university and industry" and "spin*"; "university and industry" and "network*".[1] The outcome of these searches was a total of 534 articles on U–I relations, published between 1986 and 2011.

Following the methodological approach adopted by Silva and Teixeira (2008), Silva and Teixeira (2009) and Cruz and Teixeira (2010), we examined the literature published on U–I relations and classified it by main themes/topics and types of methodologies employed. The main themes/topics considered resulted from the brief literature review conducted in Sect. 2. Thus, the 534 articles were classified into 9 topics (plus a residual category, 'Others'): 1) Characteristics of the scientists; 2) Business characteristics; 3) University characteristics; 4) Technology transfer channels; 5) Academic spin-offs; 6) Technology transfer offices (TTO); 7) Regional knowledge spillovers; 8) Science and technology policies in U–I relationships; and 9) Measures and indicators. Regarding the types of methodologies of the articles published, we considered the distinction proposed by Nelson and Winter (1982) in terms of 'formal' and 'appreciative' theorizing. In an attempt to clarify the difference between theoretical arguments that follow a mathematical logic and those that do not imply any modelling, these authors suggest that 'formal' includes

[1] The combinations used included also the several synonymous of 'university and industry', namely: 'science and industry'; 'university and firm'; and 'university and business'.

'logically structured theorizing', whereas 'appreciative' comprises a 'more intuitive' form, based on 'judgments and common sense' (Nelson and Winter, 1982: 9). Therefore, in the present study, the articles classified as 'appreciative' included critiques, judgments, appreciations, appraisals or theoretical arguments. 'Formal' articles contained mathematical models or were based on an analytical or logical framework. If these formal articles also included the testing of data in the models used, they were classified as 'formal and empirical'. If the article was only (or substantially) concerned with the econometric or statistical testing of data, we classified it as 'empirical'. Finally, when the article contained an appreciation or a comment plus empirical data analysis, it was classified as 'appreciative and empirical'. 'Survey' includes articles that overview the literature on a particular topic.

The references in the published articles (i.e., citations they made to other articles), downloaded from SciVerse Scopus, provided the basis to build the second ('roots') database. This 'roots' database encompasses 20327 references made by the articles published on U–I relations. We empirically assessed the roots or conceptual origins of U–I by determining which authors, studies, academic journals and schools of thought most contributed to the creation of knowledge within this line of research.

The third database – the 'influence' database – includes 15378 citations to the articles published on U–I, that is, over 15 thousand studies that cited the articles published on this field of research (also downloaded from SciVerse Scopus).[2] This enabled us to identify which academic journals/scientific areas and countries were most influenced by the U–I literature.

Empirical results

Articles published on U–I relations: global evolution, main outlets and most prolific authors

The number of articles published on the topic of U–I relations has increased significantly (cf. Figure 1), along the lines reported in other studies (e.g., Agrawal 2001; Rothaermel et al. 2007; Bekkers and Freitas 2008), confirming the growing interest in aspects of cooperation between U and I (Mowery et al. 2001), following the Bay-Dole Act of 1980 in the United States, a turning point in terms of policy in university licensing activities (Shane 2004). The distribution of the articles published by year is however not uniform, since there are sporadic breaks, more evident in 1999, 2006, and 2010.

Of the more than 530 articles published on U–I relations, *Research Policy* is the academic journal with the largest concentration of U–I articles (99 articles, 18.5 % of the total), followed by the *Technovation* and *Journal of Technology Transfer* (45 and 44 articles, respectively) and, at some distance, the *International Journal of Technology Management* (27 articles). *Science and Public Policy* (21 articles), the *Journal of Business Venturing* (15 articles) and *Management Science* (14 articles) also stand out (Fig. 2).

The seven academic journals mentioned above account for half of the articles which make up the database, which in total includes 139 different academic journals. These are

[2] All the cited and citing references had to be harmonized in terms of the authors' and sources' names and titles—this was a painstaking and time-consuming task but deemed necessary in order to obtain a rigorous picture of the authors and outlets that most influenced and were influenced by the U–I literature. It is worth to note that a cited work is a paper or book that has been mentioned in the references of other works, and the citing work is the one that contains the references (Garfield 1994).

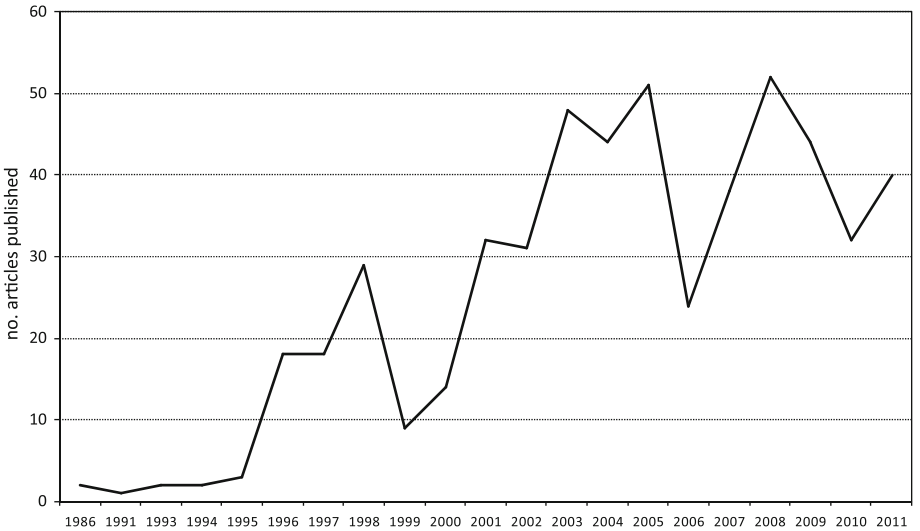


Fig. 1 Number of journal articles published on U–I between 1986 and 2011. *Note* Using a combination of keywords ("university and industry" and "linkages", "university and industry" and "technology transfer", "university and industry" and "science park*", "university and industry" and "spin*", "university and industry", "network") in the search engine of the SCOPUS bibliographic database (restricted to articles published in academic journals in the field of the Social and Human Sciences), we obtained 534 articles, published between 1986 and 2011. *Source* Authors' computations

essentially journals in the academic fields of management and business, economics and interdisciplinary areas (Social Sciences), related to the topics of innovation, R&D and technology transfer. Of the 23 journals listed, 19 are indexed on the ISI web of knowledge, reflecting a high level of quality and scientific reputation.

Donald S. Siegel (University of New York, US) is the author who has published the highest number of articles in this field (18 publications), followed by Albert N. Link (University of North Carolina, US) and Mike Wright (University of Nottingham, UK) (15 publications), and Marie C. Thursby (Georgia Institute Technology, US) (11 publications). The work of Donald S. Siegel, Albert N. Link and Marie C. Thursby focuses mainly on the issue of the entrepreneurial university, while the research interests of Mike Wright cover technology transfer and the international dimensions of entrepreneurship management and venture capital.

Articles published on U–I relationships: main topics and types

Over the entire period of our analysis, 1986–2011, the topics which inspired the greatest number of publications in the field of U–I relations (cf. Fig. 3) were 'academic spin-offs', with almost 20 % of all publications, followed by the 'knowledge transfer channels' and the 'characteristics of universities' (both with 16.1 %).

The results also suggest that the growth in the number of publications on U–I relationships has been accompanied by a change in the topics explored. In fact, although they account for a significant share of all publications, articles focusing on 'Academic spin-offs' and (to a larger extent) 'Knowledge Transfer Channels' have suffered a sharp drop in importance throughout the period. We find the same trend in the share of articles which

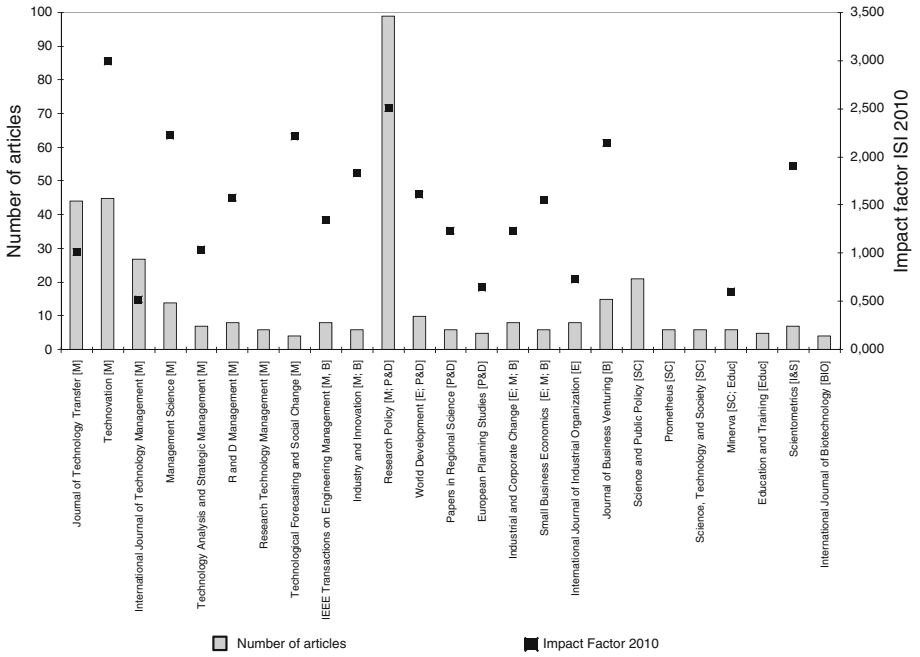


Fig. 2 Number of articles published on U–I relationships, 1986–2011, by academic journal. *Note* The 534 articles were published in 139 distinct journals. The 25 journals depicted encompass 71.3 % of total papers published. *M* Management, *B* Business, *E* Economics, *P&D* Planning and Development, *SC* Social Sciences, *Educ* Education, *I&S* Information and Science, *BIO* Biotechnology, cf. *ISI web of knowledge*. *Source* Author's computations; Impact Factor—ISI *web of knowledge* (2011 JCR *Social Science Edition*)

cover 'Science and technology policy' (which fell by almost 4 % points between the initial period and the more recent period).

In contrast, 'Characteristics of the universities', 'Characteristics of the firms' and 'Characteristics of the scientists', as well as 'Regional spillovers', have grown remarkably. 'Measures and indicators' grew, in absolute terms, by one and a half percentage points, which represented one of the sharpest increases in relative terms. In light of these results, we can state that the topics explored have focused more on the entities that are at the basis of U–I relationships (characteristics of universities, firms and scientists), addressing their motivations or success factors to engage in collaborations, be they formal or informal. Moreover, in the first half of the 2000s, TTOs have taken on a leading role as intermediaries in the transfer of knowledge (Wright et al. 2008; Yusuf 2008) and the literature has therefore pertinently focused on analyzing the efficiency of these offices. With regards to the subdivision 'Measures and indicators', more recent studies have tried to address the lack of empirical evidence on the topic of U–I relationships (Tijssen 2006; Ramos-Vielba et al. 2009), and it thus seems natural that its growth has been the sharpest in the more recent period.

Looking at the publication of articles by type (Fig. 4), we were able to assess the evolution of the formalism of the methods used in this field of research. We found that, for the period as a whole, the articles published have an essentially descriptive and argumentative nature, that is, they are of an appreciative type. In fact, articles which are

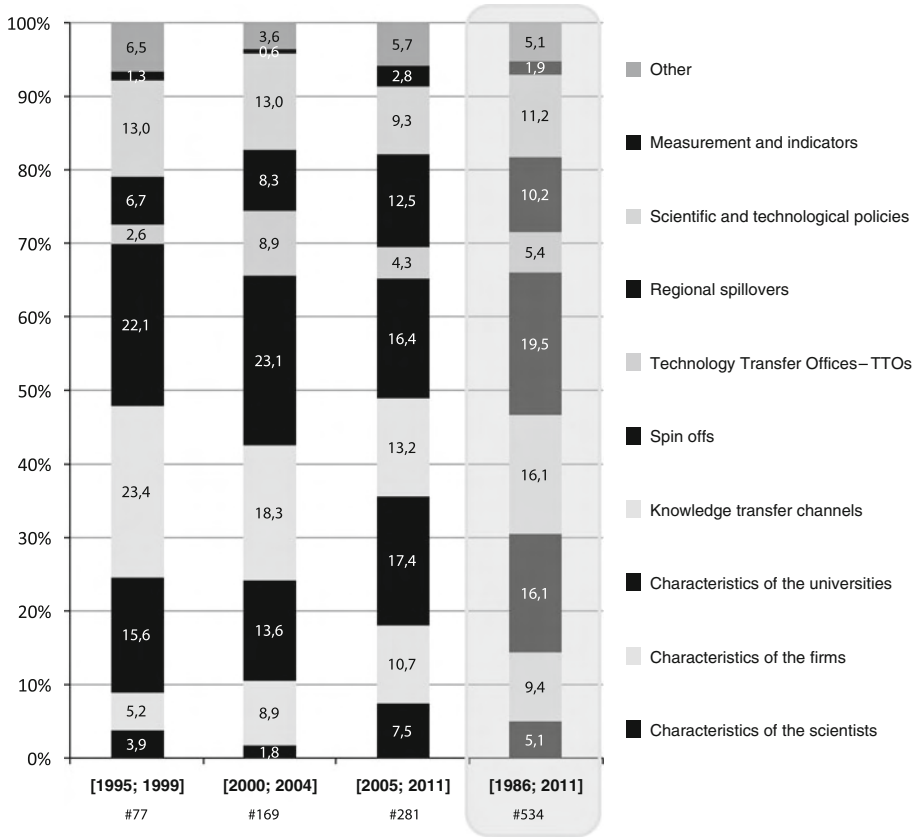


Fig. 3 Distribution of articles (%) on U–I relationships by topic (by 5-year intervals: 1986–2011). *Note* Using a combination of keywords (cf. notes in Fig. 1) in the search engine of the SCOPUS bibliographic database (restricted to articles published in academic journals in the field of the Social and Human Sciences), we obtained 534 articles, published between 1986 and 2011, on U–I links. *Source* Authors' computations

'Appreciative and empirical' (46.4 %) and 'Appreciative' (26.2 %) account for almost 73 % of all articles published, and the prevalence of these categories in all of the periods considered is clear, in line with the results suggested by Cruz and Teixeira (2010) in their analysis of the clusters literature.

We found that, alongside the remarkable increase in importance of the 'Empirical' type (from 5.2 % in the initial period to 21.4 % in 2005–2011), the importance of exclusively 'Formal' and 'Formal and Empirical' articles has decreased significantly (from 14.3 % in 1995–1999 down to 5.7 % in 2005–2011). Thus the tendency for the mathematization observed in the field of economics (Weintraub 2002) or in some of its sub-fields (structural change—Silva and Teixeira 2008; evolutionary economics—Silva and Teixeira 2009), is not confirmed in the U–I literature.

Another relevant issue to analyze when looking at the articles published on the topic of U–I links is the geographical incidence of the empirical analysis (Fig. 5). We found that the vast majority of the empirically-related articles focused on the US economy, followed at a considerable distance by the UK. This is not foreign to the fact that comparative

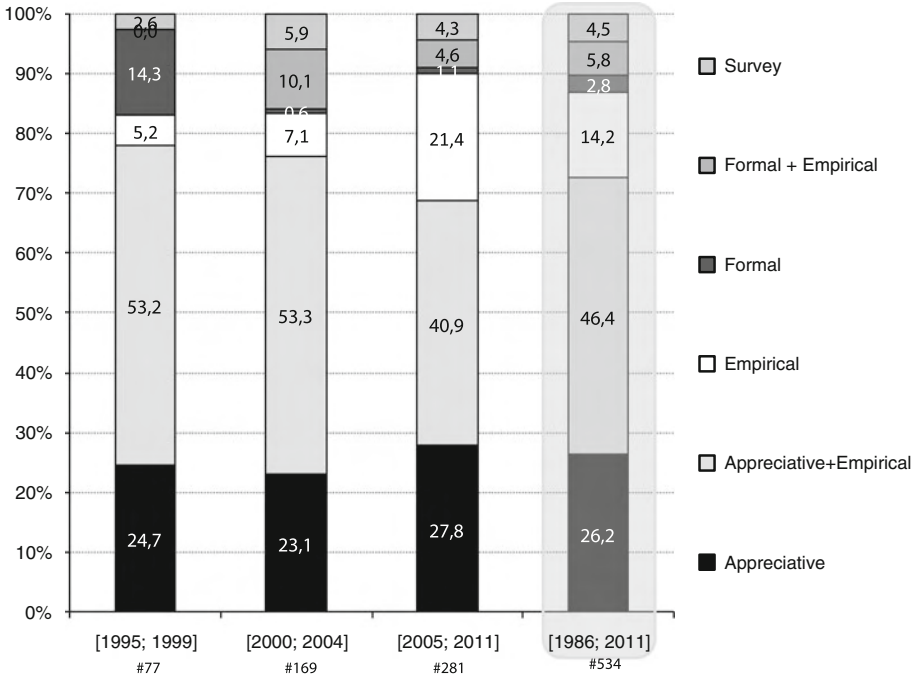


Fig. 4 Distribution of articles (%) on U–I relationships by type (by 5-year intervals: 1986–2011). *Note* Using a combination of keywords (cf. notes in Fig. 1) in the search engine of the SCOPUS bibliographic database (restricted to articles published in academic journals in the field of the Social and Human Sciences), we obtained 534 articles, published between 1986 and 2011, on U–I links. *Source* Authors' computations

studies usually took these countries, especially the US, as the benchmark. However, the US suffered a sharp decline in importance (from 37 % in the initial period, falling by 17 % points to 20 % in 2005–2011), against a growing interest for U–I relations in European (most notably Germany, Italy and the UK) and Asian countries (China and Thailand, in particular). Latin America, the Middle East and particularly Africa, are still relatively underexplored in the U–I literature.

These findings suggest that, after the initial boom in articles centred on the effects of the changes introduced by the Bayh-Dole Act of 1980 in the United States, the literature shifted its focus to other geographical areas, where the national and regional innovation systems were changing as a result of changes in policy designed to make universities more entrepreneurial (Rothaermel et al. 2007).

The scientific roots of the literature on U–I relations

Academic articles published within a given topic serve to gauge the trends and direction of recent research on that same topic (Goyal et al. 2006), comprising fundamental vehicles for the dissemination of scientific knowledge (Silva and Teixeira 2009). In turn, the references in these articles, that is, the studies they cite, serve to analyse the roots of the field (Du and Teixeira 2012).

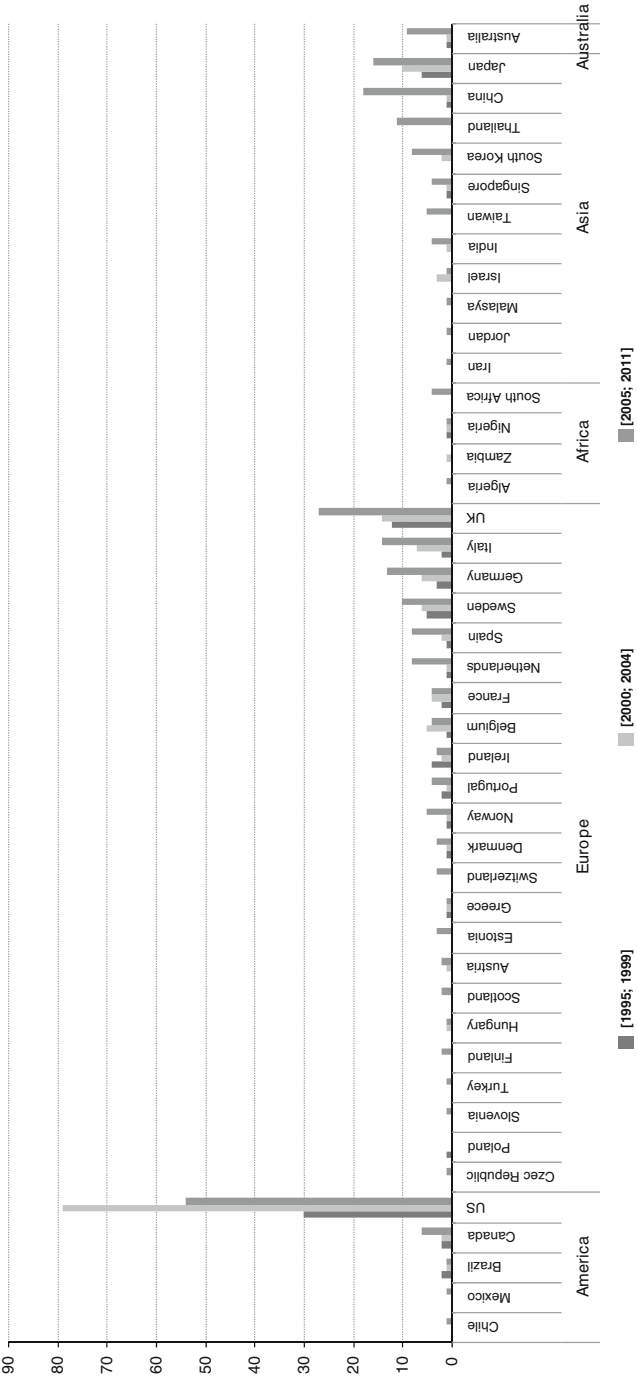


Fig. 5 Number of articles by country, 1995–2011. *Note* About 87 % of the papers published on university–industry related issues analyze one or more countries. The US, with 166 (36 % of the corresponding total) papers published, was the most studied country, followed at a considerable distance by the UK, with 54 papers (12 % of the corresponding total). *Source* Authors' computations

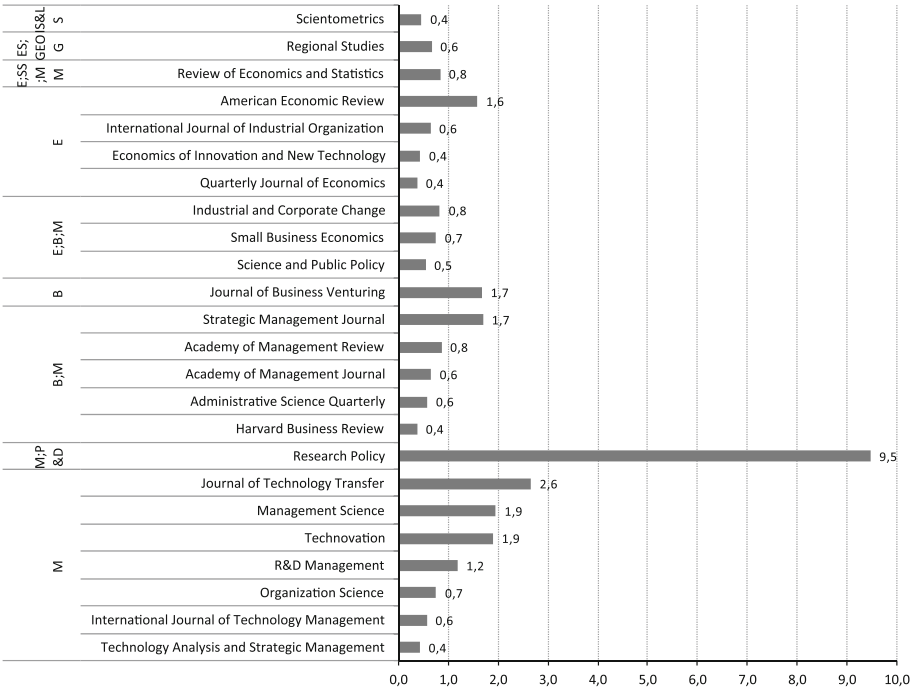


Fig. 6 The 'roots' of the U–I literature in terms of sources. *Note* The calculations were based on 20,327 references of the 534 articles related to U–I literature published between 1986 and 2011. These references comprise 6,187 distinct sources (incl. journals, conference proceedings and grey literature). The 25 listed sources constitute the most-cited sources (in % of the total) by the U–I literature and encompass 31.5 % of total cited references made by the U–I literature. *B* Business, *E* Economics, *ES* Environmental Studies, *G* Geography, *IS&LS* Information Science and Library Science, *M* Management, *P&D* Planning and Development. *Source* Authors' computations

The published studies on U–I links are relatively recent (being published mainly in the 2000–2004 period), which corroborates the idea that U–I relations is a relatively recent, separate field of research (Gulbrandsen et al. 2011).

Of a total of 20,327 references, *Research Policy* gathered the largest number of cited references (1922, 9.5 % of the total), followed by the *Journal of Technology Transfer* which presents a significantly lower number (537 cited references, 2.6 % of the total), and *Management Science* and *Technovation* (394 and 387 cited references, 1.9 % of the total). The 25 journals listed in Fig. 6 account for over one-third of the total cited references made in the U–I literature.

When we compared these results with those related to the articles published by academic journal (cf. Fig. 2), we found that *Research Policy* and the *Journal of Technology Transfer*, apart from being two of the academic journals which publish the most U–I literature, are also the most widely cited in this same literature. It is nevertheless interesting to note that about one-third of the cited references listed in Fig. 6 comes from quite top ranking and well-established outlets in economics (e.g., *American Economic Review; Quarterly Journal of Economics; Review of Economics and Statistics*) and management (e.g., *Academy of Management Journal; Academy of Management Review; Administrative*

Science Quarterly; Harvard Business Review; Organization Science; Strategic Management Journal).

The results suggest a greater concentration of cited references in academic journals that belong to the management and business areas. In other words, the scientific 'roots' of the literature on U–I relationships come mainly from the fields of management and business (17 in 25) and, to a lesser extent, economics (8 in 25).

The studies that are more extensively cited in the U–I literature (Table 1), that is, those that constitute the roots of the field, are in general relatively widely-cited studies (having received, by May 2012, over 100 citations in the Scopus or ISI bibliographic databases). It is worth highlighting that the roots of the U–I literature encompass an interesting mix of mainstream approaches, neoclassical studies (e.g., Henderson et al. 1998; Zucker et al. 1998), particularly focusing on the issues of intellectual property rights, patents and licenses, and a more heterodox type of studies related to (national) systems of innovation (e.g., Nelson 1993; Rosenberg and Nelson 1994; Etzkowitz and Leydesdorff 2000). This blend of distinct strands in the literature reflects the multidisciplinary nature of the field which, to be fully grasped, requires a wealth of knowledge on sources and contributions.

In terms of authors, the US affiliated researchers stand prominently among the top 25 listed in Fig. 7. Only 4 authors of the 25, Wright, Lockett, Trajtenberg, and Leydesdorff, the most cited in the U–I literature, are affiliated to universities outside of the US. It is interesting to note that similarly to the most-cited studies, the U–I roots include relatively well-cited researchers in terms of authors (as conveyed by the figures in the black columns in Fig. 7, which presents the number of citations each author received in the Scopus or ISI bibliographic databases). For instance, Richard R. Nelson received the highest number of cited references in the U–I literature (478 citations, cf. white columns in Fig. 7), being also one of the most cited in the literature in general (with 3,802 citations in Scopus by 14 May 2012). Henry Etzkowitz and Albert Link come next with 312 (2,081 in Scopus) and 292 (1,456 in Scopus) citations.

Taking into account the research interests of the most-cited authors, we again observe the mix of neoclassical and heterodox approaches. Indeed, Donald S. Siegel, Albert N. Link, Marie C. Thursby, Jerry G. Thursby, Maryann Feldman and J. Owen-Smith are basically researching topics related to the transfer of technology by universities and university entrepreneurialism, essentially from a neoclassical perspective. These same topics are explored by Scott Shane and Arvids A. Ziedonis, although they adopt an approach more in line with the evolutionary school. Looking at our results in this context, the most-cited authors fall into both schools of thought. The evolutionary strand related to technological change, as well as the theories of economic growth and the theory of the firm, is shared by Richard Nelson, Bhaven N. Sampat, Henry Etzkowitz or David Mowery, this last author focusing primarily on the historical processes of U–I links.

The influence of the literature on U–I relations

The vast majority of the 534 articles published in the U–I literature received (by 14 May 2012) at least 1 citation. Of the total, 459 articles on U–I relations received over 15 thousand citations. The 25 sources listed in Fig. 8 represent 53 % of the total citing references to the U–I literature. Thus, the U–I literature mostly influences the studies published in outlets such as *Research Policy* (13.8 %), *Journal of Technological Transfer* (6.3 %) or *Technovation* (5.3 %).

Based in the above findings, we concluded that the U–I field of research reveals some scientific endogamy as the outlets that publish this literature more extensively are also

Table 1 The 'roots' of U–I literature in terms of studies

Study	Citations by U–I literature	Citations by Scopus [*ISI] [**Google Scholar]	Type of source
Siegel, D.S., Waldman, D., Link, A.; Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: An exploratory study; (2003) *Research Policy*, 32 (1), pp. 27–48	74	233	Journal article
Henderson, R., Jaffe, A.B., Trajtenberg, M.; Universities as a source of commercial technology: A detailed analysis of university Patenting, 1965–1988; (1998) *Review of Economics and Statistics*, 80 (1), pp. 119–127	67	264	Journal article
Zucker, L.G., Darby, M.R., Brewer, M.B.; Intellectual Human Capital and the Birth of US Biotechnology Enterprises; (1998) *American Economic Review*, 88 (1), pp. 290–306	59	513	Journal article
Nelson R.R.; (1993), *National Innovation Systems: A Comparative Analysis*; Oxford University Press	57	5391**	Book (ed.)
Rosenberg, N., Nelson, R.R.; American universities and technical advance in industry; (1994) *Research Policy*, 23 (3), pp. 323–348.	57	312	Journal article
Jaffe, A.B.; Real effects of academic research; (1989) *American Economic Review*, 79(5), pp. 957–970	56	635*	Journal article
Thursby, J.G., Thursby, M.C.; Who is selling the ivory tower? Sources of growth in university licensing; (2002) *Management Science*, 48 (1), pp. 90–104	54	185	Journal article
Jensen, R., Thursby, M.; Proofs and prototypes for sale: The licensing of University inventions; (2001) *American Economic Review*, 91 (1), pp. 240–259	52	224	Journal article
Mowery, D.C., Nelson, R.R., Sampat, B.N., Ziedonis, A.A.; The growth of patenting and licensing by US Universities: An assessment of the effects of the Bayh-Dole act of 1980; (2001) *Research Policy*, 30 (1), pp. 99–119	51	261	Journal article
Jaffe, A.B., Trajtenberg, M., Henderson, R.; Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations; (1993) *Quarterly Journal of Economics*, 108(3), pp. 577–598	48	1300*	Journal article

Table 1 continued

Study	Citations by U–I literature	Citations by Scopus [*ISI] [**Google Scholar]	Type of source
Di Gregorio, D., Shane, S.; Why do some universities generate more start-ups than others? (2003) *Research Policy*, 32 (2 SPEC.), pp. 209–227	48	203	Journal article
Mansfield, E.; Academic research and industrial innovation; (1991) *Research Policy*, 20 (1), pp. 1–12.	42	268	Journal article
Saxenian A.; (1994), *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*; Harvard University Press	41	7157**	Book
Etzkowitz, H., Leydesdorff, L.; The dynamics of innovation: From National Systems and "mode 2" to a Triple Helix of university–industry–government relations; (2000) *Research Policy*, 29 (2), pp. 109–123	40	616	Journal article
Lundvall B.A.; (1992), *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*; Pinter	40	–	Book (ed.)
Mansfield, E.; Academic research underlying industrial innovations: sources, characteristics, and financing; (1995) *Review of Economics and Statistics*, 77 (1), pp. 55–65	39	235	Journal article
Partha, D., David, P.A., Toward a new economics of science; (1994) *Research Policy*, 23 (5), pp. 487–521	38	455	Journal article
Cohen, W.M., Nelson, R.R., Walsh, J.P.; Links and impacts: The influence of public research on industrial R&D; (2002) *Management Science*, 48 (1), pp. 1–23.	37	319	Journal article
Thursby, J.G., Jensen, R., Thursby, M.C.; Objectives, characteristics and outcomes of University Licensing: A survey of major US Universities; (2001) *Journal of Technology Transfer*, 26 (1–2), pp. 59–72.	36	142	Journal article
Agrawal, A., Henderson, R., Putting patents in context: Exploring knowledge transfer from MIT; (2002) *Management Science*, 48 (1), pp. 44–60.	36	202	Journal article
Roberts E.B., 1991, *Entrepreneurs in high technology: Lessons from MIT and beyond*; Oxford University Press	34	1045**	Book
Audretsch, D.B., Stephan, P.E.; Company-Scientist Locational Links: The Case of Biotechnology; (1996) *American Economic Review*, 86 (3), pp. 641–652.	33	304	Journal article

Table 1 continued

Study	Citations by U–I literature	Citations by Scopus [*ISI] [**Google Scholar]	Type of source
Etzkowitz, H., Webster, A., Gebhardt, C., Terra, B.R.C.; The future of the university and the university of the future: Evolution of ivory tower to entrepreneurial paradigm; (2000) *Research Policy*, 29 (2), pp. 313–330	33	253	Journal article
Cohen, W.M., Levinthal, D.A.; Innovation and Learning: The Two Faces of R & D; 1989; *Economic Journal*, 99(397), pp. 569–596	32	1356*	Journal article
Cohen W.M., Florida R., Randazzese L., Walsh J., Industry and the academy: Uneasy partners in the cause of technological advance, 1998, in *Challenges to Research Universities*, Brookings Institution Press	31	–	Book (ed.)
Arrow K.J., Economic welfare and the allocation of resources for invention, 1962, in *The Rate and Direction of Inventive Activity*, NBER	30	7363**	Book Ch.
Powell, W.W., Koput, K.W., Smith-Doerr, L.; Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology; (1996) *Administrative Science Quarterly*, 41 (1), pp. 116–145	30	1774	Journal article
Etzkowitz, H.; The norms of entrepreneurial science: Cognitive effects of the new university–industry linkages; (1998) *Research Policy*, 27 (8), pp. 823–833	29	195	Journal article
Meyer-Krahmer, F., Schmoch, U.; Science-based technologies: University–industry interactions in four fields; (1998) *Research Policy*, 27 (8), pp. 835–851	28	187	Journal article
Shane S., 2004, *Academic Entrepreneurship: University Spinoffs and Wealth Creation*, Edward Elgar	28	651**	Book

The 'roots' database (i.e., references of studies published on U–I links) includes 11,348 distinct studies and 20,423 citations made in the U–I literature. The 30 studies listed in this table represent 0.26 % of total studies listed and 6.3 % of the total citations. About 80 % of the studies received only one citation

Source Authors' computations

those that most cite it; in other words, its influence does not go beyond the restricted circle of studies on innovation and technology. Moreover, top economics and management journals (e.g., *American Economic Review; Quarterly Journal of Economics; Academy of Management Journal; Strategic Management Journal*), which constitute important roots for the U–I literature, do not seem to be influenced by the literature published in this research field.

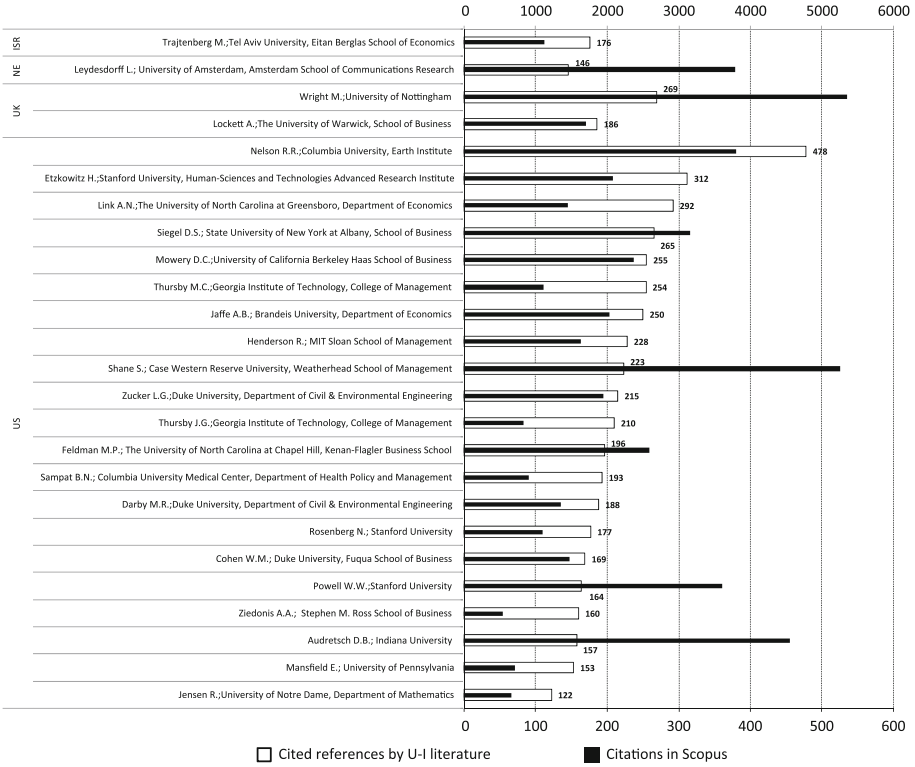


Fig. 7 The 'roots' of the U–I literature in terms of authors. *Note* The 'roots' database includes 36,299 cited references in the U–I literature to 9,434 distinct (co)authors. Only 33 authors (0.3 % of the total) received 100 or more cited references in the U–I literature. At the other extreme, the vast majority of the authors (63.7 % of the total) received only 1 citation in the U–I literature. *Source* Authors' computations

If we consider the country of affiliation of the authors that cite the U–I literature, some interesting geographical patterns of the scientific influence of this field are worth mentioning (cf. Fig. 9). Firstly, the scientific influence of the U–I literature is concentrated in the most industrialized/developed countries of the world: US (which accounts for 26 % of the total citing references), UK (14 %), Italy (8 %), and Spain (6 %). Secondly, although the influence of U–I is reasonably global (reaching 55 different countries), Africa and Asia (excluding China, Taiwan or Japan) seem to be rather excluded.

Conclusion

Universities as producers and diffusers of knowledge, most particularly the relations between Universities and Industry, have attracting increasing interest from politicians, business people and academics. Thus, a comprehensive, quantitative account of the existing literature on the topic of U–I relations may prove useful to assess the evolution of topics within the U–I literature, as well as its scientific roots and influence.

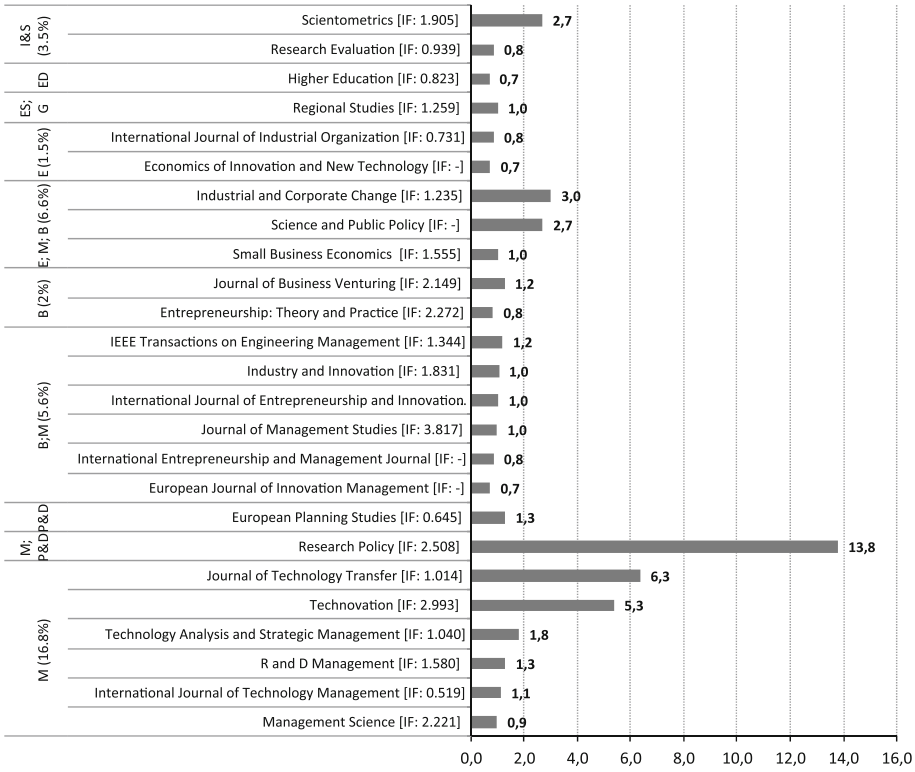
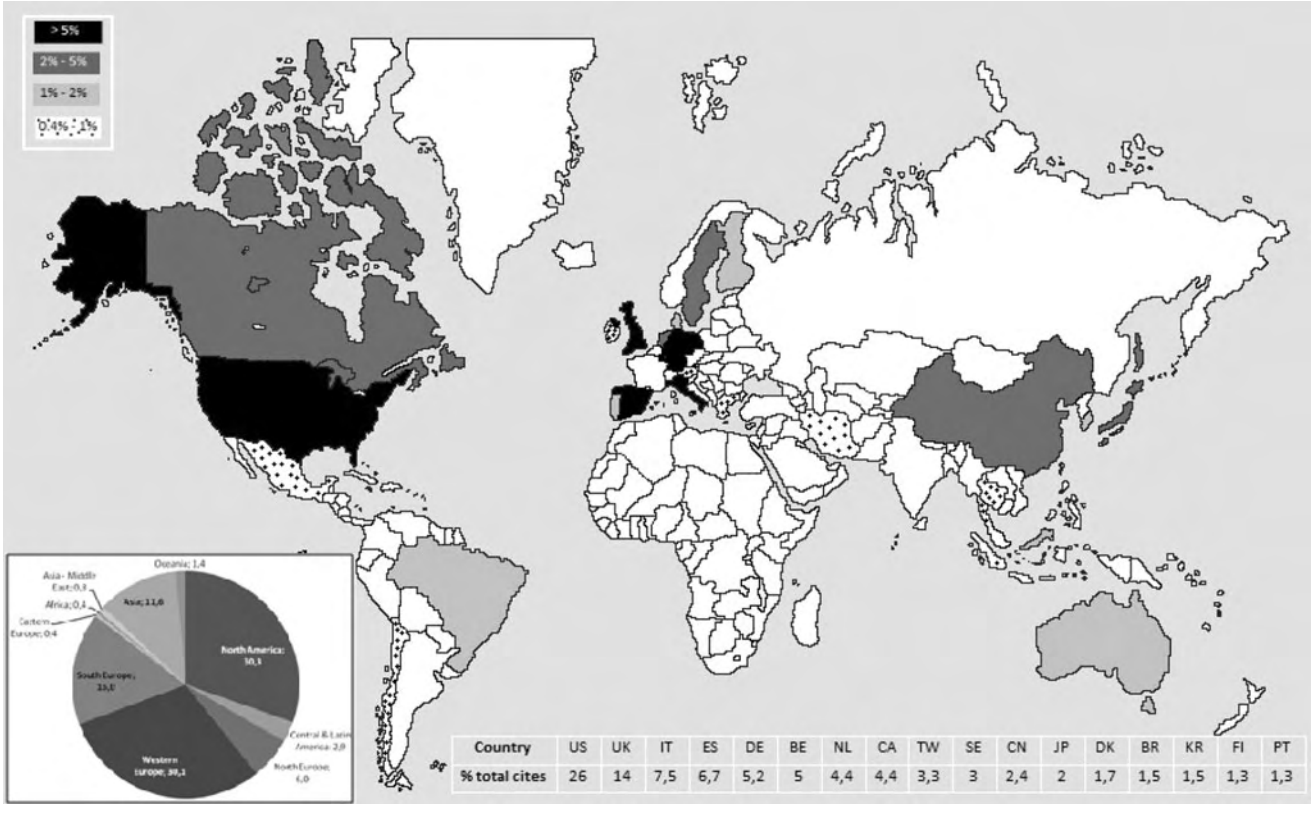


Fig. 8 The 'influence' of the U–I literature by source (in % total citing references). *Note* Numbers obtained from the 15,378 citing references to 459 (out of the 534) articles published between 1986 and 2011 on U–I links (75 articles received 0 citations). These citations were made by 1,180 distinct sources (journals, conference proceedings and handbooks), being the bulk (94 %) made by articles published in journals. The 25 sources listed (encompassing 100 or more citations) represents 52.8 % of total citations received by U–I literature. *B* Business, *E* Economics, *ES* Environmental Studies, *ED* Education, *G* Geography; *IS&LS* Information Science and Library Science, *M* Management, *P&D* Planning and Development, *IF* Impact Factor. *Source* Authors' computations; Impact Factor—ISI *web of knowledge* (2011 JCR *Social Science Edition*). *Source* Authors' computations

Three different, yet complementary, databases were constructed and analyzed: one that included all the articles (534) published on U–I relationships between 1986 and 2011, in which we classified the articles according to the subtopics explored, type of methodology adopted and also the countries/regions; a second database, including 20,327 references made by the articles published on U–I relations, which allowed us to identify the intellectual roots of the literature on U–I relationships, by listing the most influential (most cited) authors, studies and academic journals in that field; the third database, comprising 15,378 citing references to the articles published on U–I, served to assess the extent of the influence of this literature/field, by analyzing the journals and scientific fields which most widely cite the U–I literature, as well as its geographical scope of influence.

During the period of our study (1986–2011), we found a change in the topics explored, more directed at understanding the motivations or success factors of the entities involved in the knowledge transfer process (scientists, universities, companies), as well as presenting measures and indicators to assess the quantity and quality of those relationships. This



Country	US	UK	IT	ES	DE	BE	NL	CA	TW	SE	CN	JP	DK	BR	KR	FI	PT
% total cites	26	14	7,5	6,7	5,2	5	4,4	4,4	3,3	3	2,4	2	1,7	1,5	1,5	1,3	1,3

Fig. 9 The geographical 'influence' of the U–I literature. *Note* Numbers were obtained from the 15,378 citing references to 459 (of the 534, as 75 articles received 0 citations) articles published between 1986 and 2011 on U–I links. In this map, we considered the affiliation country of all (co)authors of the citing references. A total of 40,255 studies and authors' affiliations were counted originating from 55 different countries, which can be seen as the 'geographical influence' of the U–I literature. *Source* Authors' computations

change was accompanied by a growing trend towards empiricism, against formalization. In addition, in terms of applied work, we found a decrease in importance of the US in favour of analyses involving European and, especially, certain Asian countries (China, Taiwan and Thailand).

Journals in the field of innovation and technology, such as *Research Policy*, the *Journal of Technology Transfer* or *Technovation*, are the most important outlets in the literature on U–I relationships. Management-related journals dominate in terms of publications on this topic, whereas economics journals are relatively underrepresented (the leading ones include *Industrial and Corporate Change*, the *International Journal of Industrial Organization*, *World Development* and *Small Business Economics*).

Topics in decline include (in spite of their significant weight in the period as a whole) 'Academic spin-offs', 'Science and technology policy' and (to a larger extent) 'Knowledge Transfer Channels'. In contrast, 'Characteristics of universities', 'Characteristics of firms' and 'Characteristics of scientists', as well as 'Regional spillovers', grew remarkably. 'Measures and indicators' can be considered an emerging theme, given their sharp rise in relative terms, which reflects recent attempts to overcome measurement problems found in the empirical literature on U–I relationships (Tijssen 2006; Ramos-Vielba et al. 2009). This evolution is not unrelated to the trend towards empiricism observed in the methodology employed in the articles. Nevertheless, the bulk of the literature in this area is of an appreciative and empirical nature, or exclusively appreciative, with the formal and the formal and empirical types accounting for a negligible share of the articles published on U–I relationships.

In terms of the scientific fields of the main outlets, the intellectual roots of the literature on U–I relations do not differ significantly from the pattern of the publications, with the management field and, in particular, the subfield of innovation and technology emerging as the most vital. However, it is important to highlight the multidisciplinary nature of these roots, ranging from management and economics to the exact sciences, geography and planning.

Regarding the authors, although Richard Nelson, a well-known economics evolutionist, emerges as the 'founding father' of the U–I field and the historical component of the processes appears to be fairly important, as reflected in the large number of references to David Mowery, there is a clear predominance of neoclassical contributions in terms of the intellectual roots of the U–I literature.

The scope of influence of the U–I literature is essentially restricted to the subfield of innovation and technology. It is interesting to note that journals such as *Scientometrics* and *Research Evaluation*, which fall in the information sciences field, appear as reasonably 'influenced' by the literature on U–I relations. Being geographically quite global, the influence of U–I literature outside the subfield of innovation and technology is nevertheless limited.

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