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University–industry relationships and open innovation: Towards a research agenda

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Abstract

Organizations increasingly rely on external sources of innovation via inter-organizational network relationships. This paper explores the diffusion and characteristics of collaborative relationships between universities and industry, and develops a research agenda informed by an 'open innovation' perspective. A framework is proposed, distinguishing university–industry relationships from other mechanisms such as technology transfer or human mobility. On the basis of the existing body of research, the role of practices such as collaborative research, university–industry research centres, contract research and academic consulting is analysed. The evidence suggests that such university–industry relationships are widely practised, whereby differences exist across industries and scientific disciplines. While most existing research focuses on the effects of university–industry links on innovation-specific variables such as patents or firm innovativeness, the organizational dynamics of these relationships remain under-researched. A detailed research agenda addresses research needs in two main areas: search and match processes between universities and firms, and the organization and management of collaborative relationships.

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Recent studies of innovation have pointed to the growing relevance of external sources of innovation. Rather than relying on internal R&D, organizations are reported to increasingly engage in 'open innovation' (Chesbrough 2006). This means that innovation can be regarded as resulting from distributed inter-organizational networks, rather than from single firms (Coombs *et al.* 2003; Powell *et al.* 1996). In the same vein, various concepts of 'interactive' innovation have been put forward to understand the non-linear, iterative and multi-agent character of innovation processes (Kline 1985; Lundvall 1988; von Hippel 1987).

This research shows that innovation-relevant links between organizations manifest themselves as *network* relationships, as opposed to 'arm's-length', transactional market links (DeBresson and Amesse 1991;Freeman 1991; Liebeskind *et al.* 1996; Powell 1990). Many of these relationships are initiated and maintained as formally established inter-organizational arrangements, such as research and development (R&D) alliances (Hagedoorn *et al.* 2000) or innovation-centred collaboration along the supply chain (Harabi 1998). Others result from informal social relationships among members of different organizations (Gulati 1998;Oliver and Liebeskind 1998). The relevance of inter-organizational and social networks for innovation-related processes is rooted in the nature of knowledge creation as a socially embedded process (Brown and Duguid 1991; Malmberg and Maskell 2002).

If these considerations hold for innovation-related inter-organizational links in general, links between public research organizations (PROs)[2] and industrial organizations represent a special case. The generic economic and social benefits of universities, such as educating cohorts of graduates, generating scientific knowledge and creating instrumentation infrastructures, have long been recognized as an important source of industrial innovation, particularly in some industries (Cohen *et al.* 2002; Mansfield 1991; Pavitt 1991; Salter and Martin 2001). The concepts of open, networked and interactive innovation, however, would suggest that actual *relationships* between universities and industry – rather than generic *links*– play a stronger role in generating innovations.

University–industry links and their impact on innovation processes have been a longstanding object of analysis in various scholarly communities in management studies, the economics of innovation, industrial organization, the sociology of science and science studies, and science and technology policy (Agrawal 2001; Hall 2004; McMillan and Hamilton 2003; Mowery and Nelson 2004; OECD 2002; Poyago-Theotoky *et al.*2002). Factors such as changing legislative environments (Mowery and Nelson 2004), the growing number of government initiatives to promote 'translational research' (Zerhouni 2003) and public–private research partnerships (Stiglitz and Wallsten 1999) as well as increasing policy pressure for universities to help improve national economic competitiveness (Greenaway and Haynes 2000) have contributed to a growing involvement of universities with industry. This is indicated by various trends: an increasing patenting propensity by universities (Nelson 2001), growing university revenues from licensing (Thursby *et al.* 2001), increasing numbers of university researchers engaging in academic entrepreneurship (Shane 2005), a growing share of industry funding in university income (Hall 2004), and the diffusion of technology transfer offices, industry collaboration support offices and science parks (Siegel *et al.* 2003).

This paper focuses on the organizationally constituted relationships between universities and industry that underpin these trends. Such relationships are different from generic 'links' such as graduate recruitment or the use and exploitation of scientific publications or university patents within firms. Yet within the context of 'open innovation', it is precisely such relationship-intensive links that are of particular interest. It is therefore legitimate to ask what we know about such relationships, in what forms they appear and what effects they have on innovation processes.

The emphasis on actual relationships somewhat qualifies the metaphor of 'technology transfer' (Bozeman 2000). While disembedded 'transfer', i.e. the use of knowledge codified within research papers, patents or prototypes, undoubtedly occurs in some circumstances, the concepts of open, networked and interactive innovation point to the role of 'bench-level' collaboration and other types of relationships underpinning and enabling such transfer (Perkmann and Walsh 2007). Research on R&D alliances and other inter-organizational networks shows that organization-level relationships are often based on social relationships between individual organizational members (Oliver and Liebeskind 1998). Similarly, university–industry links often rely on informal and formal social links (Audretsch and Stephan 1996; Jaffe 1989; Owen-Smith and Powell 2004; Zucker and Darby 1996).

Against the backdrop of this recent interest in *relationships*, as opposed to *links* more generally speaking, we pursue the following objectives: first, to determine how university–industry relationships relate to the wider spectrum of university–industry links, and define their distinctive features; secondly, to establish empirically to what degree such inter-organizational relationships between academic and industrial organizations exist, and how they relate to other types of links; and thirdly, to identify the main forms in which the relationships are practised, and to synthesize what we know about them.

While the first objective is conceptual in nature, the latter two objectives are achieved by building on the existing body of research. The secondary evidence used is derived from a comprehensive survey of peer-reviewed empirical articles from 1990 onwards using the Web of Knowledge, EBSCO Business Premier and ABI/INFORM databases. A simplified version of the process underlying a systematic literature survey (Tranfield *et al.* 2003) was used to filter and summarize the results. Initially, a list of relevant search terms was created during a brainstorming meeting, and iteratively improved by running test searches and taking into account the results. Search terms included approximately 30 phrases, including 'university industry', 'industry collaboration', 'research collaboration', 'collaborative research' and 'consulting' used in various combinations, dictions and truncations. Further relevant references were found using the snowball principle. Summaries were generated for each article, including the main findings, methods deployed and nature of data sources, and compiled in tabular form. The search yielded 49 articles that were relevant and based on evidence of sufficient quality. From 1990 onwards, an average of two to three articles per year were published on this topic with a peak of 17 articles between 2001 and 2002, partly due to a special issue. Complementary information was taken from reports published by government agencies and other organizations.

A comment on the methodologies deployed in this literature is in order. Students of university–industry links have traditionally used quantitative data sets on patents, licensing, academic entrepreneurship and co-authoring, partly because of data availability. These allow for powerful analysis, yet do not directly account for social relationships, organizational arrangements or motivations. For instance, research based on patent data risks missing forms of collaboration that do not result in patents or areas of industrial innovation where patents do not play a primary role. This is why many of the studies reviewed here resort to survey data, collected either from academics (D'Este and Patel 2007; Louis Seashore *et al.* 1989) or industry employees (Cohen *et al.* 2002; Klevorick *et al.* 1995) or both (Lee 2000; Mansfield 1995). These studies offer significant breadth, as they capture all types of university–industry links, or even industrial R&D as a whole; yet they offer relatively little detail when it comes to characterizing relationships more in depth. Qualitative studies provide more detail (Faulkner 1994; Ham and Mowery 1998; Link 1998) yet are less suitable for providing reliable assessments of impacts and consequences. In addition, there are a series of studies that are based on data sets specifically covering university–industry collaborations (Caloghirou *et al.* 2001; Carayol 2003). These offer potentially the best insights, yet such studies are often hampered by the difficulty and cost of obtaining complete and detailed data sets.

The paper is organized as follows. First, we conceptually position relationship-based forms of university–industry interaction within the wider spectrum of such links and define their features. We then resort to the literature to determine the role that such relationships play compared with other types of links. The subsequent two sections focus on the state of research on two specific forms of university–industry relationships: research partnerships and research services (i.e. academic consulting and contract research). In the conclusion, we lay out an agenda for further research.

The Diverse Nature of University–Industry Links

Our first objective is to position university–industry relationships within the wider spectrum of science–industry links. While research on university–industry links has traditionally focused on the transfer of intellectual property (IP) (patenting, licensing, commercialization), recent observers have pointed to a more multi-faceted nature of university–industry links (Agrawal 2001; Bonaccorsi and Piccaluga 1994; Grossman *et al.*2001). They identify various 'channels' (Cohen *et al.* 2002; D'Este and Patel forthcoming; Faulkner 1994) or 'mechanisms' (Meyer-Krahmer and Schmoch 1998) that function as informational or social pathways through which information, knowledge and other resources are exchanged or co-produced across universities and industry.

Cohen *et al.* (2002), based on a survey among industrial R&D executives, distinguish between the following channels relevant to industrial innovation: patents, informal information exchange, publications and reports, public meetings and conferences, recently hired graduates, licenses, joint or co-operative research ventures, contract research, consulting, and temporary personnel exchanges. Schartinger *et al.* (2002) identify 16 types of 'knowledge interaction' grouped into four categories: joint research (including joint publishing), contract research (including consulting, financing of university research assistants by firms), mobility (staff movement between universities and firms, joint supervision of students) and training (co-operation in education, training of firm staff at universities, lecturing by industry staff).

The use of categories such as 'channels' and 'mechanisms' is sociologically imprecise. While some of the items refer to the 'media' through which information is transferred between public research and industrial realms (publications, patents), others relate to 'social processes' or 'configurations' (collaborative research, informal networks). For this reason, we suggest the use of a generic category, 'university–industry links', for designating the various ways in which publicly funded research potentially benefits industry and the economy (Salter and Martin 2001). Table 1 provides an overview of these links.

Insert Table 1 about here

Several frameworks have been suggested to capture the different dimensions of these links. First, one can distinguish between levels at which links are maintained, ranging from individual and small group links, departmental or faculty links, links managed by university-owned exploitation companies and local, regional or national consortia of higher education institutions (HEIs) (Howells *et al.* 1998). Alternatively, links can be classified according to where they stand between industry-pull (such as contract research) and university-push logics (such as spin-outs) (Poyago-Theotoky *et al.* 2002).

Though useful in some respects, these classifications fail to grasp the relational aspect of university–industry links. Schartinger *et al.* (2002) provide a suitable starting point by distinguishing between different 'channels' based on their suitability for transferring tacit knowledge and the degree to which they are based on personal face-to-face contacts. This suggests that links vary according to what can be called 'relational involvement' between universities and industrial organizations.[3]

Links with high relational involvement include situations where individuals and teams from academic and industrial contexts work together on specific projects and produce common outputs. These arrangements can be referred to as 'relationships' (Table 2). By contrast, the use of scientific publications and the licensing of university-generated IP represent links with low relational involvement, as they do not necessarily require relationships between university researchers and industry users. These latter hence come closest to what is commonly referred to as knowledge/technology 'transfer', although they can occur in conjunction with mechanisms with higher relational involvement (Agrawal 2006). Finally, links based on 'mobility' whereby individuals move between academic and industrial contexts can be classified as having intermediate relational involvement, as some links with previous colleagues are often maintained after the move. Such mobility can either be permanent, such as in the case of graduates taking up positions in industry or academics deciding to manage their own academic spin-off, or temporary, such as in the case of industrial scientists temporarily working in a university laboratory.

Insert Table 2 about here

In the context of 'open innovation', it is particularly the links with high relational involvement that are of interest, as they facilitate the building and maintenance of inter-organizational relationships over a prolonged period of time. It is this type of arrangement that is usually implied by accounts that depict the network and not single organizations as the 'locus of innovation' (Powell *et al.* 1996). In their analysis of the biotechnology industry, Powell *et al.* (1996) make a case for a learning-centred view of inter-organizational collaboration. They assume that decisions to collaborate are not make-or-buy decisions made on the basis of balancing costs and risks with the expected benefits. Rather, collaboration is embedded in communities of learning that transcend the boundaries of single organizations; firm learning therefore occurs by participation in such communities.

This paper's focus is on university–industry *relationships* as opposed to mobility and transfer links, because they provide a window on interactive innovation processes as described by this broader literature. Relationships will often occur in conjunction with human mobility: for example, when companies sponsor Ph.D. studentships. In fact, in many cases, mobility can be intrinsic to relationships if it occurs within the context of specific collaborative projects. By contrast, human mobility aimed at transferring generic skills, such as graduates seeking work in industry, is part of a more infrastructural role of universities and is therefore not classified under the relationship category.

Equally, relationships often precede or follow formal IP transfer activities, yet they are analytically distinct. While there is already a considerable body of research on IP commercialization, including university patenting (Hicks *et al.* 2001; Thursby and Thursby

2002) and licensing (Bercovitz *et al.* 2001; Jensen and Thursby 2001; Thursby and Thursby 2004), the literature on relationships is less consolidated. From a policy viewpoint, the promotion of collaborative research and university–industry research centres and the involvement of industrial partners in academic research projects have become important concerns for government. For instance, UK figures show that income of HEIs from collaborative research outstrips their income from IP by 13 times (Department for Employment and Learning (DfEL) 2005). Similarly, income from consulting activities is more than seven times greater than income from IP (DfEL 2005).

What Role Do University–Industry Relationships Play?

While the last section explored where inter-organizational relationships between universities and industry can be positioned conceptually, in this section we ask empirically what role relationship-based university–industry links play in relation to other links, such as transfer or mobility. Of particular interest are the following questions. First, how frequently and under what circumstances are relationship-based mechanisms used? Secondly, how important are university–industry relationships compared with other links, notably transfer-based mechanisms such as licensing which tend to be prioritised by policy discourse and research attention? Thirdly, what is the contribution of relationships to industrial innovation in more general terms, i.e. beyond the 'supply' of scientific inventions and technology breakthroughs? Fourthly, why do firms engage in university–industry relationships?

On the first question, the literature emphasizes the varied nature of university–industry links and points out that they are often used simultaneously and in succession. Among these, in many scientific disciplines and economic sectors, relationships figure prominently. For instance, on the basis of qualitative evidence on three different industries (biotechnology, ceramics, parallel computing), Faulkner and Senker (1994) emphasize the diversity of university–industry links both within and across sectors by distinguishing between three types of 'channels': literature, personal contacts and recruitment. A considerable body of quantitative evidence confirms the varied nature of university industry links. Roessner (1993), drawing on a survey among US R&D executives, reports that industry scientists built and maintained relationships with government-funded laboratories in a variety of ways. Among these, they valued contract research most highly, followed by co-operative research, while licensing was in general not considered to have the greatest value. The relatively low relevance of formal IP transfer via licensing compared with other types of interaction between PROs and industry is confirmed by a range of other studies (Cohen *et al.* 2002; Klevorick *et al.* 1995; Levin*et al.* 1987; Mansfield 1991; Pavitt 1991) and mirrored by attitudinal studies on the main individual motivators for university–industry collaboration (Lee 1996).

In a survey-based study covering universities and industrial respondents, Schartinger *et al.* (2002) reveal widespread use of university–industry relationships in the Austrian context, particularly in the natural sciences and engineering and their associated industrial sectors. Similarly, Meyer-Krahmer and Schmoch (1998) report the results of a survey among German academics on the importance of various types of links with industry, finding that collaborative research and informal contacts were valued most highly. Similarly, D'Este and Patel (2007) present data on university–industry interaction channels for the UK. On the basis of a survey among academics in the sciences and engineering disciplines, they conclude that researchers use a wide variety of such channels, such as consultancy and contract research, joint research, training, meetings and conferences, and the 'creation of new physical facilities' (e.g. 'spin-off' companies). They find that a significant number of academics are engaged in several channels simultaneously, particularly in the applied sciences. Age, professorial status and involvement in patenting are positively correlated with a higher propensity to interact with industry. In addition, collaboration is not predicted by high rankings of university departments; by contrast, lower-ranked departments appear to generate more interactions (D'Este and Patel 2007).

These studies confirm that relationship-based mechanisms are widely used by PROs and industrial organizations. Yet there are systematic differences between industrial sectors and academic fields in terms of the predominant linking mechanisms. This goes beyond the fact that some sectors depend on science to a larger degree, with the pharmaceutical, biotechnology and chemical sectors ranging among the most 'science-intensive' sectors according to several measures (Cohen *et al.* 2002; Faulkner and Senker 1994; Klevorick *et al.* 1995). In fact, the level and modalities of university–industry relationships cannot simply be mapped onto the distinction between science-intensive sectors and those that are not. For instance, US results indicate that, while collaborative research or research joint ventures are considered important in diverse sectors such as pharmaceuticals, steel, TV/radio and aerospace, academic consulting is highly relevant in various sectors such as food, medical equipment, petroleum, metals, search/navigational equipment and pharmaceuticals (Cohen *et al.* 2002, 16). Schartinger *et al.* (2002) also show that the picture is complex in the sense that, among the sectors with the highest interaction intensity are, on the one hand, those with high R&D ratios (chemicals, instruments) and, on the other, sectors with low R&D ratios such as energy, basic metals, construction and agriculture. They find considerable differences between the underlying interaction modes, with specific types of relationships clustering within certain disciplines and sectors. For instance, collaborative research is preferred to contract research in the chemicals, instruments, metals and automotive sectors, while the opposite is true for software development. Training and education, by contrast, are used mainly by the service industry. Similar evidence is provided by Meyer-Krahmer and Schmoch (1998) for Germany; they show that 'open science' channels[4] are predominant in the chemical industry, while the mechanical engineering sector mostly relies on contract research and consulting. In addition, in chemicals, education and personnel transfer were more important, building on a historic tradition in this sector in Germany.

Regardless of some disparities between different surveys, we conclude that, in science-based sectors such as pharmaceuticals, biotechnology or chemicals, with strong complementarities between academic research and firm R&D, firms tend to rely on collaborative research – an open science channel – as well as research services (contract research and consulting) that have stronger commercial features. By contrast, sectors emphasizing incremental improvement rather than scientific breakthroughs, such as mechanical engineering or software development, show a preference for research services.

Our second question asked how important relationships are compared with other links with lower relational involvement, in particular licensing and transfer of codified knowledge. Cohen *et al.* (2002) find that open science channels are in general far more relevant to industrial R&D laboratories than the commercial activities of universities, such as licensing or co-operative ventures. Apart from the use of publications and informal interaction, they count consulting, contract research and joint research among open science channels (Cohen *et al.* 2002). Although this can be disputed – considering the IP-related restrictions associated with some of these activities – most of them are in fact characterized by high relational involvement.

Even in the pharmaceutical and biotechnology industries where university-generated IP is more important than in other sectors (Mansfield 1995), relationship-based links are considered relatively more important by R&D executives (Cohen *et al.* 2002). This is echoed by Meyer-Krahmer and Schmoch (1998), who emphasize that bidirectional knowledge interaction mechanisms, i.e. those based on relationships, are judged as more important than unidirectional knowledge transfer by both academics and industrial scientists. The prevalence of relationships, combined with the moderate importance of codified knowledge artefacts such as patents and other IP, suggests that the notion of technology transfer that figures prominently in many policy recommendations and practices is somehow flawed.

Some indicative conclusions on the relative importance of relationship-based mechanisms can also be drawn from figures on university funding. In the UK, industry, commerce and public corporations account for approximately 7% of the total research income of UK HEIs (DfEL

2005).[5] Across the EU15, the share of business-funded R&D performed in higher education and government laboratories (HERD) was 6.6% in 2002–2003.[6]

In the US, industry funding provided for university research has risen strongly over the 1980s and 1990s, albeit from a relatively low level (Hall 2004).[7] This trend was driven by US federal policies aimed at addressing the diminishing competitiveness of US companies in the 1980s (Jankowski 1999).

Although these figures might appear low, due to public match-funding provided for many industry-involving projects, approximately 20–25% of academic research might be directly influenced by industrial funding (Behrens and Gray 2001). For instance, 43% of the UK Government's Engineering and Physical Sciences Research Council grants by value involve formal collaboration with a third party (DfEL 2005, 25).

Universities also allocate considerable resources to facilitating interaction with industry. For instance, 4000 staff full-time equivalents at UK HEIs manage so-called 'third-stream' activities aimed at the needs of businesses and other organizations (DfEL 2005). Many are concerned with the facilitation and administration of activities such as contract research, consulting or collaborative research. More HEIs have an internal department for managing academic consulting than for the exploitation of IP (DfEL 2005, 15), and 66% of HEIs have a contracting system for staff–business consulting activities. These figures illustrate the quantitative relevance of relationship-based arrangements such as research partnerships and research services. By contrast, university income from the commercialization of Intellectual Property amounts to just over 7% of the income for collaborative partnerships, although it should be noted that a considerable proportion of that latter income is derived from government grants.

The relative importance of university–industry relationships compared with mobility-based links, i.e. the transfer of staff and students, is more difficult to gauge. In general, the 'production' of skilled graduates by universities is one of the most highly valued benefits of academic research for industrial organizations (Dasgupta and David 1994; Salter and Martin 2001). Yet the discussion of such generic benefits – to which a different set of measures apply – is beyond the scope of this paper, which focuses on whether and how companies work more directly with universities within an open innovation scenario.

On the third question, there is evidence that relationship-based mechanisms contribute to industrial innovation processes in a broader sense than just delivering university-generated inventions and breakthrough technologies. In many cases, public research provides ways of solving problems rather than suggesting new project ideas (Cohen *et al.* 2002). This is consistent with 'non-linear' views of the innovation process championed by Kline and Rosenberg (1986) and von Hippel (1986) that emphasize the role of downstream development or consumers and buyers. Similar evidence is provided by studies that show that 'bread-and-butter' activities such as consulting and contract research are widely practised and judged important by both academics and industrial R&D executives (Cohen *et al.* 2002; Meyer-Krahmer and Schmoch 1998). Rather then cutting-edge research, consulting and contract research tend to provide more common yet specialized expertise required especially at the latter stages of the innovation cycle, such as product differentiation and improvement (Polt *et al.* 2001). As these represent the volume segment of innovation activities, one can expect them to be relevant for the innovation performance of economies as a whole. The differences between types of activities pursued might explain inconsistent evidence on the effect of university–industry relationships on firm innovativeness: for instance, with respect to whether universities contribute to product or process innovation (Fontana *et al.* 2006).

Notably, consulting activities are relevant for SMEs the majority of which do not pursue formal R&D activities. This provides the rationale for government-sponsored initiatives such as 'manufacturing extension partnerships' (Shapira 2001) in the USA, or outreach activities pursued by universities (Macpherson and Ziolkowski 2005). The latter authors' case study suggests that 'outreach activities' by universities can have positive impacts on incremental innovation activities within local firms.

Fourthly, various studies indicate that firms' motives for engaging in university–industry links are informed by generic benefits such as accessing students, gaining 'windows' on emerging technologies and enhancing their knowledge base rather than by the desire to develop specific commercializable innovations (Caloghirou *et al.* 2001; Feller 2005). As a result, firms often choose not to assess the value of these relationships via hard performance measures (Ham and Mowery 1998) and are not concerned about making a quantitative case for participation (Feller *et al.* 2002). Although this is due partly to the practical difficulties in quantitatively assessing the value of participating in PRO research (Feller *et al.* 2002), one can argue that the desire by firms to generate tangible innovation outcomes from university–industry links only tells part of the story. This means performance measures such as patents, licenses or spin-offs promoted by the emerging technology transfer profession do not necessarily reflect the whole range of anticipated benefits. To a degree this is because most collaborative research is subsidized by public funds, *de facto* lowering the cost to companies of participating in such initiatives. Some degree of opportunistic engagement can be expected in some cases, as for instance found by Feller *et al.* (2002), who note that company participation (in university–industry research centres) was relatively fragile, and likely to be discontinued when the public funds for the initiative dried up. Nevertheless, anecdotal evidence suggests the retention of industrial membership in several long-standing partnerships has remained high, and universities continue aggressively to seek industrial sponsorship (Feller 2005). As with question three, the overall evidence on this question is thinly spread, and further research and analysis are warranted.

In summary, these points extracted from existing research paint a rich picture of university–industry links that leads us away from the simplified 'technology transfer' or 'knowledge transfer' metaphors that are deployed in policy discourse. First, a wide variety of interaction mechanisms ('channels') are deployed, with systematic differences across industries. Secondly, there is consensus that patents and other university-generated IP are only moderately important for innovation processes, with relationship-based mechanisms exceeding them in terms of relevance. Thirdly, the contribution of university-generated knowledge is not limited to novel inventions and radical innovations but is also relevant for the latter stages of the innovation cycle. Finally, firms' motives for participating in university–industry links vary, but are generally not limited to the desire to generate and access readily commercializable innovations.

What We Know About University–Industry Relationships

In this section, we undertake a detailed exploration of relationship-based forms of university–industry links. We distinguish between two main types, depending on the degree of finalization of the research undertaken: 'research partnerships' and 'research services'. The concept of finalization refers to the degree to which scientific research pursues a specific (technical, social or economic) purpose as opposed to gaining new knowledge for the sake of itself (Weingart 1997). With respect to activities that are partially or wholly funded by industry, there is a continuum as to how finalized the research is, ranging from industrial contributions made available for 'blue-sky' research to explicitly commissioned research and consulting activities with specified objectives and outcomes (Figure 1). This distinction also resonates with the difference between the generation of new, leading edge knowledge and the application and diffusion of expertise that is commonly held within specific academic communities (Agrawal and Henderson 2002). To a degree, the distinction also goes hand in hand with the difference between 'open' and 'commercial' science, in the sense that research partnerships often imply weaker appropriation opportunities for industrial partners than do research services where all intellectual outputs are usually appropriated by the commissioning organization.

Insert Figure 1 about here

In light of these considerations, *research partnerships* are designed to generate outputs that are of high academic relevance and can therefore be used and adapted for academic publications by the researchers involved. Research partnerships include collaborative research activities, also known as sponsored research, and university–industry research centres. *Research services*, by contrast, are provided by academic researchers under the direction of industrial clients and tend to be less exploitable for academic publications. Contract research and some academic consulting fall under this category. It should be noted that both types of collaborative activities will often be practised simultaneously, and different institutions might classify the same activities in different ways (Schmoch 1999). Nevertheless the following discussion aims to bring conceptual order to a multiplex reality that can provide starting points for empirical operationalization.

Research Partnerships

Research partnerships are formal collaborative arrangements among organizations with the objective to co-operate on research and development activities. While many research partnerships involve firms only (Audretsch and Feldman 2003; Hagedoorn *et al.* 2000), the emphasis here is on partnerships between PROs and firms. They are characterized as 'private–public' partnerships by some authors (Audretsch *et al.*2002); others see them as private–private partnerships as long as they do not receive some level of support from a public institution (Link *et al.* 2002). In practice, the distinction is not overly relevant, as most research partnerships are in fact assisted by public funds within the context of policy programmes by national, regional or supranational authorities (Poyago-Theotoky *et al.* 2002; Stiglitz and Wallsten 1999).

University–industry partnerships can range from small-scale, temporary projects to permanent, large-scale organizations with hundreds of industrial members. Despite the presence of highly publicized, large-scale strategic partnerships, for instance between pharmaceutical companies and US research universities (Stephan 2001), the volume of such partnerships is represented by smaller projects initiated and managed by individual university researchers and their research groups. Such *collaborative research* arrangements, also often referred to as 'industry-sponsored research', particularly in the medical field, involve varying degrees of industry involvement in university research, ranging from funding and guiding research to, though less frequently, actual 'bench-level' co-operative work.[8] An overview of relevant studies of research partnerships is given in Table 3.

Insert Table 3 about here

In many cases, collaborative research is subsidized by public policy programmes. In Europe, the 'framework programmes' of the European Commission provide resources for collaborative projects involving universities and firms (Caloghirou *et al.* 2001; Larédo and Mustar 2004; Peterson and Sharp 1998). They are mirrored in the USA by federal-funded schemes such as the Advanced Technology Programme (ATP) (Hall *et al.* 2000), various funding instruments provided by research councils, government departments and the National Health Service in the UK (Howells *et al.* 1998) and joint university–industry projects within federal programmes in Germany (Schmoch 1999).

The objective to induce more bench-level co-operation among university and industry researchers has been the main driver to establish university–industry research centres as partnerships with common facilities. Typically, such centres are co-funded by the participating firms and government. In the USA, as of 1990, there were more than one thousand university–industry R&D centres, of which most (60%) were established during the 1980s (Cohen *et al.* 1994, cited in Lee 1996). The centres spent $2.9 billion on R&D (Cohen *et al.* 1994). A number of policies facilitated the emergence of these centres, such as the schemes for Science and Technology Centres (S&TCs) and the Engineering Research Centres (ERCs), both funded by the National Science Foundation. The ERCs are aimed at developing fundamental knowledge crucial for the competitiveness of firms, and include an educational element (Adams *et al.* 2001). There are also a number of centres funded by the National Institutes of Health (NIH) in the pharmaceutical/medical field.

The evidence on university–industry research centres in other countries is more limited. An OECD (2002) publication points out that the UK has a long history of joint R&D establishments and anecdotally refers to some examples, such as the Hitachi Research Laboratory at Cambridge, and centres supported by GlaxoSmithKline and British Nuclear Fuels. Other examples are the Rolls Royce network of University Technology Centres (UTCs) and the Systems Engineering Innovation Centre at Loughborough University funded by BAE SYSTEMS (Brown and Ternouth 2006). Rolls-Royce UTCs are located at various universities, whereby each UTC deals with a specific piece of engine technology. Within the centres, university-based groups work alongside the company's own research and engineering teams (Treasury 2003). In the Netherlands, a government programme supported the establishment of 'Leading Technology Institutes', mostly 'virtual' networks of PROs and industrial organizations in specific technology areas. They are governed via a ticket system that allows firms to buy 'tickets' to increase their say in decisions on the research pursued (OECD 2003).

The evidence on the impact of research partnerships on industrial firms is relatively limited. Adams *et al.* (2001) analyse USA university–industry research centres across all industries and find some limited evidence that they promote technology transfer by increasing patenting rates at the associated industrial laboratories. The centres tend to stimulate a range of activities such as co-authoring between university and industry members (indicating collaborative research), academic consulting, applied R&D, educational outputs in addition to classic technology transfer, i.e. patents, licences and spin-off companies (Adams *et al.*2001). For Europe, evidence suggests that firms that screen scientific publications and are involved in public policies have more collaborative relationships with universities (Fontana *et al.* 2006), but this does not indicate whether the relationships are effective. Among the few existing case studies is a study of a US research joint venture project in electronics where a considerable reduction in overall R&D costs and a reduction of development times was achieved (Link 1998).

Research Services: Contract Research and Consulting

Contract research and academic consulting are paid-for services performed by university researchers for external clients. In comparison with research partnerships, these relationships are more asymmetric in the sense that firms determine unilaterally what type of expertise or service they require, and the researcher carries out the assignment against payment. Whereas grants given by industrial sponsors for collaborative research allow for some degree of academic freedom, research or consulting contracts define specific objectives and deliverables. The non-financial benefits of the latter will therefore be enjoyed mainly by the industrial partner although, notably in the definition phase of projects, universities will learn about technological contexts and problems within the firm as well as previous research results obtained by the firm (Schmoch 1999).

Although in practice the boundaries between the two activities are blurred, consulting exploits existing expertise, while in contract research the industrial client commissions the academic researcher to explore specific, previously unresearched aspects of a problem. This type of interaction has comparatively low entry costs, requires low levels of absorption capacity and is among the few types of interaction that spatially cluster (Schartinger *et al*. 2002).

In general, three types of arrangements can be distinguished. First, individual and informal arrangements appear to dominate in the Anglo-Saxon systems but are also practised in other countries. For instance, many universities in the US, UK and Germany provide incentives to staff for providing consulting services, for instance by stipulating that they are free to spend a certain amount of their time, usually approximately 20%, on outside activities (Schmoch 1999). Revenue goes to the university or the research group, the researcher personally or a combination. The evidence is obscured by the fact that an unknown share of these activities is not reported to departments and university administrations. Secondly, examples such as the 'research divisions' system at the Catholic University of Leuven constitute university-level arrangements. The research divisions operate as semi-autonomous units organized by disciplines and areas of expertise through which most of the organization's contract research is carried out (Debackere and Veugelers 2005). Finally, the Fraunhofer Gesellschaft in Germany reflects a nationally established system of organizations that routinely engage in contract research for industrial clients (Beise and Stahl 1999).

From the academics' viewpoint, research services differ from research partnerships in that they involve work that is usually of lesser academic value (Boyer and Lewis 1984). This is highlighted by a UK survey on motivating factors for industry–academic collaboration, suggesting that barriers to establishing consultancy links are somewhat different from those for collaborative research reflecting different incentive structures (Howells *et al.* 1998). The fact that consulting work was 'not interesting' was ranked top, and the lack of career impact was third in importance, behind difficulties recruiting suitable industrial partners. At the same time, 'differences in objectives' was only ranked fourth, indicating that academics accommodate the fact that consulting has to reflect the industry's needs compared with collaborative research. However, evidence from Belgium indicates that researchers involved in contract research generally published more, and their research was not skewed towards applied topics compared with their 'pure' academic colleagues (Van Looy*et al.* 2004). The dissonances arising from the evidence indicate a need for further research in this area.

While recent in-depth research on this issue is scarce, there is an older literature on faculty consulting in the US (Boyer and Lewis 1984; Louis Seashore *et al.* 1989; Marsh and Dillon 1980; Patton and Marver 1979;Rebne 1989; Teague 1982). The primary question addressed by this literature was whether faculty consulting represented 'responsibility or promiscuity' (Boyer and Lewis 1984). Traditionally viewed as an important form of public service, increasing consulting activities had raised fears that professors would neglect their university responsibilities over their outside activities. Boyer and Lewis's (1984) review of the main issues suggests that academic consulting was 'overestimated and underappreciated'. Their data show that only between 12 and 20% of faculty staff was actually involved in consulting activities, whereby supplemental income added approximately 14% to their salaries. This is consistent with data from the 1970s showing that for life scientists the supplemental income achieved by consulting was approximately 10% of their academic salary (Louis Seashore *et al.* 1989). Boyer and Lewis (1984) also argue that economic motives were not primary in academics' decisions to engage in consulting,[9] and that consulting academics are at least as active within the universities as their non-consulting peers.

More recent research on consulting is not available at this level of detail, but it would certainly be of considerable interest to compare these assessments with current trends. As Hall (2004) points out, 'this type of collaboration is largely unstudied and uncaptured'. In the same vein, Cohen *et al.* (2002) note that, although little-studied, consulting scores relatively highly among R&D executives as a vehicle through which public research affects industrial R&D.

Conclusions

Summary of Findings

In this review, we argued that in contexts of open and networked innovation, inter-organizational relationships between public research organizations and industry play an important role in driving innovation processes. We provided a typology to position such relationships against other types of university–industry links, i.e. transfer mechanisms and human mobility. The evidence suggests that such relationships are widespread and are regarded as valuable by both industrial and academic participants. Specifically, it appears that the contribution of relationships to innovative activities in the commercial sector considerably exceeds the contribution of IP transfer (e.g. licensing).

As to the absolute diffusion of university–industry relationships, the empirical evidence is limited, yet there are indications that they are common at least in some disciplines. In the survey by d'Este and Patel (2007), approximately 55% of respondent academics in the scientific and engineering disciplines in receipt of public research funds in the UK had some experience with collaborating with industry. While this figure may be skewed due to self-selection effects, it suggests collaborating with industry is common in these disciplines while other evidence confirms the same for the life science disciplines (Blumenthal *et al.* 1996; Lee 2000;Owen-Smith *et al.* 2002).

Relationships include research partnerships, contract research and consulting, where the evidence suggests that firms value these relationships over the whole innovation cycle and not just for the initial supply of inventions. In fact, from the viewpoint of the firm, the role of 'ready-made', university-generated technology is moderate compared with the value of the above-mentioned relationship-based activities. This is underlined by the fact that firms' expectations towards collaboration tend to be informed by capacity-building and learning motives rather than tangible outcomes, an attitude that is promoted by public subsidies for most research partnerships. Presumably, expected outcomes are more tangible in the case of research services which are fully paid for by companies. No detailed empirical evidence exists, however, on the differences between firms' knowledge-sourcing strategies focused on research partnerships and those focused on research services.

On a general note, much existing work prioritizes the study of the effects of university–industry links on private-sector innovative activity often by using data on patents, publications, licensing and other tangible innovation inputs or outputs. Within the general context of 'open innovation' and based on an extensive review of the literature, we argue that more attention needs to be paid to the specificities and roles of networked inter-organizational relationships between firms and universities to help resolve the open questions in this area of research.

An Agenda for Further Research

The open innovation hypothesis can serve as a useful reference point for guiding further research. If it is correct that firms increasingly innovate by using external knowledge and resources, and transfer-based links between firms and universities play an only moderate role, this provides a strong rationale for studying inter-organizational networks. Inter-organizational networks can be defined as formally established co-operation arrangements spanning different organizations (Alter and Hage 1993; Freeman 1991; Powell and Grodal 2005). One can argue that the generation of innovations will result predominantly from formalized arrangements although informal, inter-personal networks might have acted as antecedents and continue to underpin the organization-level relationships. This is particularly relevant at a time when universities are becoming increasingly aware of the value of their IP and are keen to ensure that protective formal mechanisms are in place when academics collaborate with industry (Feller 2005).

The open innovation research agenda (West *et al.* 2006) suggests the following avenues of enquiry: first, search and match processes preceding university–industry relationships; and secondly, the organization and management of collaboration arrangements (Table 4).

Insert Table 4 about here

On the first issue, search and match processes, the benefit of open innovation for a firm is that specific technology needs can be better matched by searching for external assets or expertise as opposed to generating them internally. However, such benefits will only be realized if firms adopt search routines (Laursen and Salter 2006) suitable to match their specific requirements. Research is needed into how such search styles of firms are constituted. Matching rarely occurs as the result of a search involving complete information on the whole range of options available to a firm. Rather, search processes are socially selective in the sense that they are likely to be influenced by existing inter-personal networks and/or previous inter-organizational collaborations (Liebeskind *et al.* 1996; Powell *et al.* 1996), even though screening of the scientific literature appears to be a predictor of university collaboration for firms (Fontana *et al.* 2006).

What difference does it make to the search behaviour of firms as to how widely and deeply their research scientists are networked into the scientific community? In this respect, it is an open question as to what types of networks influence firms' search for university partners. Among the potential candidates, there are geographically proximate social networks (Jaffe 1989; Owen-Smith and Powell 2004), 'invisible colleges' (Crane 1972; Powell and Grodal 2005) or education-related networks such as alumni networks (Saxenian *et al.* 2002). Furthermore, traded inter-dependencies may dominate in situations where universities act as (lead) users of products which are subsequently commercially developed (Rosenberg 1992; von Hippel 1976).

A follow-on question arising from the networked nature of search processes is the relationship between, on one hand, the type of networks leading to collaboration and, on the other, the type of innovation activities pursued and innovation outputs achieved. Is formal collaboration precipitated via exposure to a large number of individuals, as in a weak ties scenario, or rather via integration into tightly knit scientific communities, as in a strong ties scenario (Granovetter 1973)? While the former scenario constitutes a case of benefiting from variety effects (exploration), the latter privileges sustained knowledge creation (exploitation) (March 1991). In this respect, it appears worthwhile investigating the role of intermediaries and brokers in establishing network relationships (Allen 1977).

The second main area for further research is the organization and management of university–industry collaboration. There are several relevant levels of analysis. On an individual level, the question is how the different incentive structures for academic researchers and industry staff can be aligned to produce mutually beneficial results. Generally, scientists are oriented towards the reputation-based reward system of open science, while industry scientists face the commercial imperative to produce exploitable results (Dasgupta and David 1994). In science-based sectors such as pharmaceuticals and biotechnology, many corporations encourage their basic researchers to interact with academia (Cockburn and Henderson 1998). However, in many other industries, the misalignment of incentives poses potential challenges for collaboration. Among the trade-offs facing academic researchers is the difference between pursuing leading-edge science and offering common expertise to industrial partners via consulting. In many cases, the industrial value of academic input consists in expertise commonly held within academic communities, i.e. 'old science' (Agrawal and Henderson 2002; Allen 1977; Rosenberg 1994) and not in leading-edge science. Recent government and university policies generally promote both types of university–industry links yet they follow different logics.

Despite these conceptual question marks, research partnerships and research services are widely practised, and one might speculate that potential incentive misalignments matter less than is presumed by observers. This indicates the need for further research. Possible explanations include differences in personal responses to incentives, differences in career trajectories and the inter-departmental division of labour between individuals pursuing different goals.

On an organizational level, university–industry relationships vary considerably in terms of contractual arrangements and outputs, which makes them difficult to research. Not much is known about the different types and diffusion of such agreements (Hall 2004) and their organizational morphologies (Bozeman and Dietz 2001). In addition, most research on university–industry research centres focuses on centres that are promoted within specific government programmes. This means that centres that are funded under different programmes or, more importantly, independently from government programmes, are not accounted for. Furthermore, what kind of research is conducted within such partnerships? Empirical research needs to address the question of what benefits are produced by different types of relationships, including formal innovation outputs, such as patents or new product launches, and more intangible benefits such as signalling effects (Spence 1974) or the building of social capital (Nahapiet and Ghoshal 1998).

A related issue is what strategies firms use to establish and manage university–industry relationships in an 'open innovation' scenario. There is some anecdotal evidence that large firms increasingly engage in more strategic and long-term partnerships with universities to benefit from the outcomes of academic research (Brown and Ternouth 2006; Staropoli 1998; Webster and Swain 1991). Research needs to explore what approaches firms use to establish such partnerships, what interfaces they establish within their R&D and other departments to exploit them and what evaluation measures they put in place. For instance, one can assume that firms differ in terms of their collaboration styles: Some firms might change their partners relatively frequently to adjust the external capabilities to their technology needs, while others might prefer long-term collaboration with the same partners. This might be reflected in different types of 'network of innovators' bridging the boundaries of firms and universities (Powell and Grodal 2005). If this is the case, what are the differences between firms with respect to innovation outcomes, and types of innovative activity pursued?

On an institutional level of analysis, much existing research is nationally confined and fails therefore to address how existing institutional structures and national innovation systems shape organizational arrangements for university–industry collaboration. Comparative research on biotechnology has revealed systematic differences between Europe and the US in terms of the 'integrative and relational capacities' of different systems to exploit life sciences research for commercial purposes (Owen-Smith *et al.* 2002). This indicates that prevailing institutions shape the way university–industry relationships are conducted (Owen-Smith 2005). For instance, in terms of public research funding, there appears to be a divide between systems that put major emphasis on basic research (the US) and systems that provide for stronger finalization, such as the German system with its Fraunhofer institutes and polytechnics (Beise and Stahl 1999). Given the disputed nature of the 'European paradox', indicating a possible failure to 'convert' basic research into technological advantage (Tijssen and van Wijk 1999; Dosi *et al.* 2006), further empirical research should shed light on the impact of these various institutional context factors on the extent and type of relationships between academic and industrial organizations.

The more general question is whether institutional and organizational conditions can and should be reconfigured to make academia more responsive to technological or industry needs, while leaving intact the 'scientific commons' (Feller 2005; Nelson 2004). In this respect, our distinction between – mostly publicly subsidized – research partnerships and research services might help interpret the mixed evidence in the literature on whether industrial involvement reduces or increases the academic productivity of the university scientists involved and changes the direction of research towards more 'applied' science (Florida and Cohen 1999; Geuna 2001; Thursby and Thursby 2004; Van Looy *et al.* 2004).

Finally, the question is whether public funding merely replaces industry R&D investment or the research conducted is in fact additional to R&D that firms would have carried out without government support (Abramovsky *et al.* 2004). There is evidence that at least some types of public support stimulate R&D and commercialization, as for instance the US Small Business Innovation Research (SBIR) programme (Audretsch *et al.* 2002), although this is disputed by other accounts (Wallsten 2000). However, such programmes fund private-sector R&D and not specifically public–private research partnerships. There is still little evidence as to whether the latter partnerships are effective in their own terms (Stiglitz and Wallsten 1999). Research is also needed on the appropriate indicators and measures to account for the impact of partnerships both organizationally and for society as a whole (Bozeman and Dietz 2001).

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Notes

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2 We use the term 'university' to include all types of 'public research organizations' (PROs). These are research organizations that are predominantly government-funded, i.e. universities, public research laboratories, research institutes, etc.

3 Thanks to one of the referees for helping to clarify this discussion.

4 'Open science' refers to knowledge-sharing mechanisms based on the traditional conventions in science, i.e. the free sharing of knowledge unhindered by commercial considerations.

5 According to OECD figures, 6.6% (MSTI database, May 2005).

6 OECD, MSTI database, May 2005.

7 In the US, the share is 2.9%, yet this underestimates the actual contribution because public sector R&D only covers federally funded R&D activities, and capital expenditures are not included (OECD, MSTI database, May 2005).

8 In the US, the term 'research joint ventures' is also used, although this includes industry–industry collaboration. Research joint ventures are defined by the US National Co-operative Research Act (1984) and its extension, the National Cooperative Research and Production Act (Vonortas 2000) as any activity by two or more persons for research purposes (Bozeman 2000) and refers to arrangements that are not equity based (Hagedoorn and Schakenraad 1992).

9 This is confirmed by Patton and Marver (1979) and Jones (2000).

References

Abramovsky, L., Kremp, E., López, A., Schmidt, T. and Simpson, H. (2004). Under-standing co-operative R&D activity: evidence from four European countries. Institute of Fiscal Studies Working Paper 05/23,London.

Adams, J.D., Chiang, E.P. and Starkey, K. (2001). Industry–university cooperative research centers. *Journal of Technology Transfer*, **26**(1–2), 73–86.

Agrawal, A. (2001). University-to-industry knowledge transfer: literature review and unanswered questions. *International Journal of Management Reviews*, **3**, 285–302.

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

Agrawal, A. and Henderson, R.M. (2002). Putting patents in context: exploring knowledge transfer from MIT. *Management Science*, **48**(1), 44.

Allen, T.J. (1977). *Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information within the R&D Organization*. Cambridge, MA: MIT Press.

Alter, C. and Hage, J. (1993). *Organizations Working Together*. Newbury Park, London: Sage.

Audretsch, D. and Feldman, M. (2003). Small-firm strategic research partnerships: the case of biotechnology. *Technology Analysis & Strategic Management*, **15**(2), 273–288.

Audretsch, D.B. and Stephan, P.E. (1996). Company–scientist locational links: the case of biotechnology. *American Economic Review*, **86**, 641–652.

Audretsch, D.B., Link, A. and Scott, J. (2002). Public/private technology partnerships: evaluating SBIR-supported research. *Research Policy*, **31**, 145–158.

Behrens, T.R. and Gray, D.O. (2001). Unintended consequences of cooperative research: impact of industry sponsorship on climate for academic freedom and other graduate student outcome. *Research Policy*, **30**, 179–199.

Beise, M. and Stahl, H. (1999). Public research and industrial innovations in Germany. *Research Policy*, **28**, 397–422.

Bercovitz, J., Feldman, M., Feller, I. and Burton, R. (2001). Organizational structure as a determinant of academic patent and licensing behavior: an exploratory study of Duke, Johns Hopkins, and Pennsylvania state universities. *Journal of Technology Transfer*, **26**(1–2), 21–35.

Blumenthal, D., Campbell, E.G., Causino, N. and Louis, K.S. (1996). Participation of life-science faculty in research relationships with industry. *New England Journal of Medicine*, **335**, 1734–1739.

Bonaccorsi, A. and Piccaluga, A. (1994). A theoretical framework for the evaluation of university–industry relationships. *R&D Management*, **24**(3), 229–247.

Boyer, C.M. and Lewis, D.R. (1984). Faculty consulting: responsibility or promiscuity? *Journal of Higher Education*, **55**, 637–659.

Bozeman, B. (2000). Technology transfer and public policy: a review of research and theory. *Research Policy*, **29**, 627–655.

Bozeman, B. and Dietz, J.S. (2001). Strategic research partnerships: constructing policy-relevant indicators. *Journal of Technology Transfer*, **26**, 385–393.

Brown, J.S. and Duguid, P. (1991). Organizational learning and communities-of-practice: toward a unified view of working, learning, and innovation. *Organization Science*, **2**, 40–57.

Brown, R. and Ternouth, P. (2006). *International Competitiveness: Businesses Working with UK Universities*. London: The Council of Industry and Higher Education.

Caloghirou, Y., Tsakanikas, A. and Vonortas, N.S. (2001). University–industry cooperation in the context of the European framework programmes. *Journal of Technology Transfer*, **26**(1–2), 153–161.

Carayol, N. (2003). Objectives, agreements and matching in science–industry collaborations: reassembling the pieces of the puzzle. *Research Policy*, **32**, 887–908.

Chesbrough, H.W. (2006). Open innovation: a new paradigm for understanding industrial innovation. In Chesbrough, H.W., Vanhaverbeke, W. and West, J. (eds), *Open Innovation: Researching a New Paradigm*. Oxford: Oxford University Press.
Cockburn, I.M. and Henderson, R.M. (1998). Absorptive capacity, coauthoring behavior, and the organization of research in drug discovery. *Journal of Industrial Economics*, **46**(2), 157–182.
Cohen, S.B., Florida, R. and Coe, W.R. (1994). *University–Industry Partnerships in the US*. Pittsburgh: Carnegie-Mellon University.
Cohen, W.M., Nelson, R.R. and Walsh, J.P. (2002). Links and impacts: the influence of public research on industrial R&D. *Management Science*, **48**(1), 1–23.
Coombs, R., Harvey, M. and Tether, B.S. (2003). Analysing distributed processes of provision and innovation. *Industrial & Corporate Change*, **12**, 1125–1155.
Crane, D. (1972). *Invisible Colleges: Diffusion of Knowledge in Scientific Communities*. Chicago: University of Chicago Press.
Dasgupta, P. and David, P.A. (1994). Toward a new economics of science. *Research Policy*, **23**, 487–521.
Debackere, K. and Veugelers, R. (2005). The role of academic technology transfer organizations in improving industry science links. *Research Policy*, **34**, 321–342.
DeBresson, C. and Amesse, F. (1991). Networks of innovators: a review and introduction to the issue. *Research Policy*, **20**, 363–379.
D'Este, P. and Patel, P. (2007). University–industry linkages in the UK: what are the factors underlying the variety of interactions with industry? Research Policy, in press.
DfEL (2005). *Higher Education-Business and Community Interaction Survey 2002–03*. London: Department for Employment and Learning.
Dosi, G., Llerena, P. and Labini, M.S. (2006). The relationships between science, technologies and their industrial exploitation: an illustration through the myths and realities of the so-called 'European paradox'. *Research Policy*, **35**, 1450–1464.
Faulkner, W. (1994). Conceptualizing knowledge used in innovation: a second look at the science–technology distinction and industrial innovation. *Science, Technology, and Human Values*, **19**(4), 425–458.
Faulkner, W. and Senker, J. (1994). Making sense of diversity: public–private sector research linkage in three technologies. *Research Policy*, **23**, 673–695.
Feller, I. (2005). A historical perspective on government–university partnerships to enhance entrepreneurship and economic development. In Shane, S. (ed.), *Economic Development through Entrepreneurship: Government, University and Business Linkages*. Cheltenham: Edward Elgar.
Feller, I., Ailes, C.P. and Roessner, J.D. (2002). Impacts of research universities on technological innovation in industry: evidence from engineering research centers. *Research Policy*, **31**, 457–474.
Florida, R. and Cohen, W.M. (1999). Engine or infrastructure? The university role in economic development. In Branscomb, L.M., Kodama, F. and Florida, R. (eds), *Industrializing Knowledge: University–Industry Linkages in Japan and the United States*. Cambridge, MA: MIT Press.
Fontana, R., Geuna, A. and Matt, M. (2006). Factors affecting university–industry R&D collaboration: the importance of screening and signalling. *Research Policy*, **35**, 309–229.
Freeman, C. (1991). Networks of innovators: a synthesis of research issues. *Research Policy*, **20**, 499–514.
Geuna, A. (2001). The changing rationale for European university research funding: are there negative unintended consequences? *Journal of Economic Issues*, **35**(3), 607.
Granovetter, M. (1973). The strength of weak ties. *American Journal of Sociology*, **78**, 1360–1380.

Greenaway, D. and Haynes, M. (2000). *Funding Universities to Meet National and International Challenges*. Nottingham: School of Economics Policy Report, University of Nottingham.
Grossman, J.H., Reid, P.P. and Morgan, R.P. (2001). Contributions of academic research to industrial performance in five industry sectors. *Journal of Technology Transfer*, **26**(1–2), 143–152.
Gulati, R. (1998). Alliances and networks., *Strategic Management Journal*, **19**, 293.
Hagedoorn, J., Link, A.N. and Vonortas, N.S. (2000). Research partnerships. *Research Policy*, **29**, 567–586.
Hagedoorn, J. and Schakenraad, J. (1992). Leading companies and networks of strategic alliances in information technologies. *Research Policy*, **21**, 163–190.
Hall, B.H. (2004). University–industry partnerships in the United States. In Contzen, J.-P., Gibson, D. and Heitor, M.V. (eds), *Rethinking Science Systems and Innovation Policies. Proceedings of the 6th International Conference on Technology Policy and Innovation*. Ashland, OH: Purdue University Press.
Hall, B.H., Link, A.N. and Scott, J.T. (2001). Barriers inhibiting industry from partnering with universities: evidence from the Advanced Technology Program. *Journal of Technology Transfer*, **26**(1), 87–98.
Ham, R.M. and Mowery, D.C. (1998). Improving the effectiveness of public–private R&D collaboration: case studies at a US weapons laboratory. *Research Policy*, **26**, 661–675.
Harabi, N. (1998). Innovation through vertical relations between firms, suppliers and customers: a study of German firms. *Industry and Innovation*, **5**(2), 157–181.
Hicks, D., Breitzman, T., Olivastro, D. and Hamilton, K. (2001). The changing composition of innovative activity in the US – a portrait based on patent analysis, *Research Policy*, **30**, 681–703.
Howells, J., Nedeva, M. and Georghiou, L. (1998). *Industry–Academic Links in the UK*. Manchester PREST: University of Manchester.
Jaffe, A.B. (1989). Real effects of academic research. *American Economic Review*, **79**, 957–970.
Jankowski, J. (1999). Trends in academic research spending, alliances, and commercialization. *Journal of Technology Transfer*, **24**(1), 55–68.
Jensen, R. and Thursby, M. (2001). Proofs and prototypes for sale: the licensing of university inventions. *American Economic Review*, **91**, 240–259.
Jones, L. (2000). *The Commercialization of Academic Science: Conflict of Interest for the Faculty Consultant*. University of Minnesota.
Klevorick, A.K., Levin, R.C., Nelson, R.R. and Winter, S.G. (1995). On the sources and significance of interindustry differences in technological opportunities. *Research Policy*, **24**, 185–205.
Kline, S.J. (1985). Innovation is not a linear process. *Research Management*, **28**(4), 36–45.
Kline, S.J. and Rosenberg, N. (1986). An overview of innovation. In Landau, R. and Rosenberg, N. (eds), *The Positive Sum Strategy*. Washington: Washington National Academy Press.
Larédo, P. and Mustar, P. (2004). Public sector research: a growing role in innovation systems. *Minerva*, **42**(1), 11–27.
Laursen, K. and Salter, A. (2006). Open for innovation: the role of openness in explaining innovation performance among UK manufacturing firms. *Strategic Management Journal*, **27**(2), 131–150.
Lee, Y.S. (1996). 'Technology transfer' and the research university: a search for the boundaries of university–industry collaboration. *Research Policy*, **25**, 843–863.
Lee, Y.S. (2000). The sustainability of university–industry research collaboration: an empirical assessment. *Journal of Technology Transfer*, **25**(2), 111–133.
Levin, R.C., Klevorick, A.K., Nelson, R.R., Winter, S.G., Gilbert, R. and Griliches, Z. (1987). Appropriating the returns from industrial research and development; comments and discussion. *Brookings Papers on Economic Activity*, **1987**(3), 783–831.

Liebeskind, J.P., Oliver, A.L., Zucker, L. and Brewer, M. (1996). Social networks, learning, and flexibility: sourcing scientific knowledge in new biotechnology firms. *Organization Science*, **7**, 428–443.
Link, A.N. (1998). Case study of R&D efficiency in an ATP joint venture. *Journal of Technology Transfer*, **23**(2), 43–15.
Link, A.N., Paton, D. and Siegel, D.S. (2002). An analysis of policy initiatives to promote strategic research partnerships. *Research Policy*, **31**, 1459–1466.
Louis Seashore, K., Blumenthal, D., Gluck, M. and Stoto, M.A. (1989). Entrepreneurs in academe: an exploration of behaviors among life scientists. *Administrative Science Quarterly*, **34**(1), 110–131.
Lundvall, B.-Å. (1988). Innovation as an interactive process: from user–producer interaction to the national system of
innovation. In Dosi, G., Freeman, C., Silverberg, G. and Soete, L. (eds), *Technical Change and Economic Theory*. London: Pinter.
Macpherson, A. and Ziolkowski, M. (2005). The role of university-based industrial extension services in the business performance of small manufacturing firms: case-study evidence from western New York.*Entrepreneurship and Regional Development*, **17**(6), 431.
Malmberg, A. and Maskell, P. (2002). The elusive concept of localization economies: towards a knowledge-based theory of spatial clustering, *Environment and Planning A*, **34**, 429–449.
Mansfield, E. (1991). Academic research and industrial innovation. *Research Policy*, **20**, 1–12.
Mansfield, E. (1995). Academic research underlying industrial innovations: sources, characteristics, and financing. *Review of Economics and Statistics*, **77**(1), 55–65.
March, J.G. (1991). Exploration and exploitation in organizational learning. *Organization Science*, **2**, 71–87.
Marsh, H.E. and Dillon, K.E. (1980). Academic productivity and faculty supplemental income. *Journal of Higher Education*, **51**, 546–555.
McMillan, G.S. and Hamilton, R.D. (2003). The impact of publicly funded basic research: an integrative extension of Martin and Salter. *IEEE Transactions on Engineering Management*, **50**(2), 184–191.
Meyer-Krahmer, F. and Schmoch, U. (1998). Science-based technologies: university–industry interactions in four fields. *Research Policy*, **27**, 835–851.
Mowery, D.C. and Nelson, R.R. (eds) (2004). *Ivory Tower and Industrial Innovation: University–Industry Technology Before and After the Bayh–Dole Act*. Stanford: Stanford University Press.
Nahapiet, J. and Ghoshal, S. (1998). Social capital, intellectual capital, and the organizational advantage. *Academy of Management Review*, **23**(2), 242–266.
Nelson, R.R. (2001). Observations on the post-Bayh–Dole rise of patenting at American universities. *Journal of Technology Transfer*, **26**(1–2), 13–19.
Nelson, R.R. (2004). The market economy, and the scientific commons. *Research Policy*, **33**, 455–471.
OECD (2002). *Benchmarking Industry–Science Relationships*. Paris: Organisation for Economic Co-operation and Development.
OECD (2003). *Public–Private Partnerships for Research and Innovation: An Evaluation of the Dutch Experience*. Paris: Organisation for Economic Co-operation and Development.
Oliver, A.L. and Liebeskind, J.P. (1998). Three levels of networking for sourcing intellectual capital in biotechnology: implications for studying inter-organisational networks. *International Studies of Management and Organization*, **27**(4), 76–103.
Owen-Smith, J. (2005). Trends and transitions in the institutional environment for public and private science. *Higher Education*, **49**(1), 91–117.
Owen-Smith, J. and Powell, W.W. (2004). Knowledge networks as channels and conduits: the effects of spillovers in the Boston biotechnology community. *Organization Science*, **15**, 5.

Owen-Smith, J., Riccaboni, M., Pammolli, F. and Powell, W.W. (2002). A comparison of us and European university–industry relations in the life sciences. *Management Science*, **48**(1), 24–43.
Patton, C.V. and Marver, J.D. (1979). Paid consulting by American academics. *Educational Record*, **60**(2), 175–184.
Pavitt, K. (1991). What makes basic research economically useful? *Research Policy,* **20**, 109–119.
Perkmann, M. and Walsh, K. (2007). How firms source knowledge from universities: partnerships versus contracting (forthcoming). In Bessant, J., and Venables, T. (eds), *Creating Wealth from Knowledge*.Cheltenham: Edward Elgar.
Peterson, J. and Sharp, M. (1998). *Technology Policy in the European Union*. Basingstoke: Macmillan.
Polt, W., Rammer, C., Gassler, H., Schibany, A. and Schartinger, D. (2001). Benchmarking industry–science relations: the role of framework conditions. *Science and Public Policy*, **28**(4), 247–258.
Powell, W.W. (1990). Neither market nor hierarchy: network forms of organization. *Research in Organizational Behaviour*, **12**, 295–336.
Powell, W.W. and Grodal, S. (2005). Networks of innovators. In Fagerberg, J., Mowery, D., and Nelson, R. (eds), *Oxford Handbook of Innovation*. Oxford: Oxford University Press.
Powell, W.W., Koput, K.W. and Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: networks of learning in biotechnology. *Administrative Science Quarterly*, **41**(1), 116.
Poyago-Theotoky, J., Beath, J. and Siegel, D.S. (2002). Universities and fundamental research: reflections on the growth of university–industry partnerships. *Oxford Review of Economic Policy*, **18**(1), 10–21.
Rea, D.G., Brooks, H., Burger, R.M. and LaScala, R. (1997). The semiconductor industry – model for industry/university/government cooperation. *Research-Technology Management*, **40**(4), 46–54.
Rebne, D. (1989). Faculty consulting and scientific knowledge – a traditional university–industry linkage. *Educational Administration Quarterly*, **25**(4), 338–357.
Roessner, J.D. (1993). What companies want from the Federal labs. *Issues in Science and Technology*, **10**(1), 37–42.
Rosenberg, N. (1992). Scientific instrumentation and university research. *Research Policy,* **21**, 381–390.
Rosenberg, N. (1994). *Exploring the Black Box: Technology, Economics, and History*. Cambridge: Cambridge University Press.
Salter, A.J. and Martin, B.R. (2001). The economic benefits of publicly funded basic research: a critical review. *Research Policy*, **30**, 509–532.
Saxenian, A.L., Motoyama, Y. and Quan, X. (2002). *Local and Global Networks of Immigrant Professionals in Silicon Valley*. San Francisco: Public Policy Institute of California.
Schartinger, D., Rammer, C., Fischer, M.M. and Fröhlich, J. (2002). Knowledge interactions between universities and industry in Austria: sectoral patterns and determinants. *Research Policy*, **31**, 303–328.
Schmoch, U. (1999). Interaction of universities and industrial enterprises in Germany and the United States – a comparison. *Industry and Innovation*, **6**(1), 51.
Shane, S.A. (2005). *Economic Development Through Entrepreneurship: Government, University and Business Linkages*. Cheltenham: Edward Elgar.
Shapira, P. (2001). US manufacturing extension partnerships: technology policy reinvented? *Research Policy*, **30**, 977.
Siegel, D.S., Waldman, D. and Link, A. (2003). Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: an exploratory study. *Research Policy*, **32**,27–48.
Spence, A.M. (1974). *Market Signalling: Informational Transfer in Hiring and Related Screening Processes*. Cambridge, MA: Harvard University Press.

Staropoli, C. (1998). Cooperation in R&D in the pharmaceutical industry – the network as an organizational innovation governing technological innovation. *Technovation*, **18**(1), 13–23.
Stephan, P.E. (2001). Educational implications of university–industry technology transfer. *Journal of Technology Transfer*, **26**(3), 199–205.
Stiglitz, J. and Wallsten, S. (1999). Public–private technology partnerships: promises and pitfalls. *American Behavioral Scientist*, **43–73**(1), 52.
Teague, G.V. (1982). Faculty consulting: do universities have 'control'? *Research in Higher Education*, **17**(2), 179–186.
Thursby, J.G. and Thursby, M.C. (2002). Who is selling the ivory tower? Sources of growth in university licensing. *Management Science*, **48**(1), 90–104.
Thursby, J.G. and Thursby, M.C. (2004). Are faculty critical? Their role in university–industry licensing. *Contemporary Economic Policy*, **22**(2), 162–178.
Thursby, J.G.A., Jensen, R.A. and Thursby, M.C.A. (2001). Objectives, characteristics and outcomes of university licensing: a survey of major us universities. *Journal of Technology Transfer*, **26**(1), 59–72.
Tijssen, R.J.W. and van Wijk, E. (1999). In search of the European paradox: an international comparison of Europe's scientific performance and knowledge flows in information and communication technologies research. *Research Policy,* **28**, 519–543.
Tranfield, D., Denyer, D. and Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management*, **14**(3),207–222.
Treasury, H. (2003). *Lambert Report of University–Industry Collaboration – Final Report*. London: Her Majesty's Stationery Office.
Van
Looy, B., Ranga, M., Callaert, J., Debackere, K. and Zimmermann, E. (2004). Combining entrepreneurial and scientific performance in academia: towards a compounded and reciprocal Matthew-effect?*Research Policy*, **33**, 425–441.
Von Hippel, E. (1976). The dominant role of users in the scientific instrument innovation process. *Research Policy,* **5**, 212–239.
Von Hippel, E. (1986). Lead users: a source of novel product concepts. *Management Science,* **32**(7), 791–805.
Von Hippel, E. (1987). *The Sources of Innovation*. New York: Oxford University Press.
Vonortas, N.S. (2000). Multimarket contact and inter-firm cooperation in R&D. *Journal of Evolutionary Economics*, **10**(1–2), 243–271.
Wallsten, S.J. (2000). The effects of government-industry R&D programs on private R&D: the case of the small business innovation research program. *RAND Journal of Economics*, **31**(1), 82–100.
Webster, A. and Swain, V. (1991). The pharmaceutical industry: towards a new innovation environment. *Technology Analysis & Strategic Management*, **3**(2), 127–142.
Weingart, P. (1997). From 'finalization' to 'mode 2': old wine in new bottles? *Social Science Information,* **36**, 591–613.
West, E., Vanhaverbeke, W. and Chesbrough, H.W. (2006). Open innovation: a research agenda. In Chesbrough, H.W., Vanhaverbeke, W., and West, J. (eds), *Open Innovation: Researching a New Paradigm*.Oxford: Oxford University Press.
Zerhouni, E. (2003). The NIH roadmap. *Science*, **302**(5642), 63–72.
Zucker, L.G. and Darby, M.R. (1996). Star scientists and institutional transformation: patterns of invention and innovation in the formation of the biotechnology industry. *Proceedings of the National Academy of Sciences*, **93**, 12709–12716.

Table 1. University–industry links

Research partnerships	Inter-organizational arrangements for pursuing collaborative R&D
Research services	Activities commissioned by industrial clients including contract research and consulting
Academic entrepreneurship	Development and commercial exploitation of technologies pursued by academic inventors through a company they (partly) own
Human resource transfer	Multi-context learning mechanisms such as training of industry employees, postgraduate training in industry, graduate trainees and secondments to industry, adjunct faculty
Informal interaction	Formation of social relationships and networks at conferences, etc.
Commercialization of property rights	Transfer of university-generated IP (such as patents) to firms, e.g. via licensing
Scientific publications	Use of codified scientific knowledge within industry

Table 2. A typology of university–industry links

Extent of relational involvement		
High: relationships	Medium: mobility	Low: transfer
Research partnerships Research services	Academic entrepreneurship Human resource transfer	Commercialisation of IP (e.g. licensing)
Use of scientific publications, conferences & networking (can accompany all forms)		

Table 3. Studies of research partnerships

Type of partnership	Object of analysis	Countries	Authors
Collaborative research	EU framework programmes	EU	Caloghirou et al. 2001
	Collaborative Research and Development Agreements (CRADAs)	US	Ham and Mowery 1998
	Research joint ventures (broadly speaking)	US	Link et al. 2002
	Case study of ATP-funded project	US	Link 1998
	Collaboration strategies of firms	EU	Fontana et al. 2006
University-industry research centres	Engineering Research Centres	US	Feller et al. 2002
	Industry-University Cooperative Research Centers	US	Adams et al. 2001
	SEMATECH, case study	US	Rea *et al.* 1997
Several types	Study of 46 collaborations several European countries and in the US	EU, US	Carayol 2003
	University-industry partnerships	US	Cohen *et al.* 1994

Table 4. Research agenda: university–industry relationships in an open innovation scenario

Search and match processes	• Role of networks mechanisms: proximity, invisible colleges, education networks, ser-producer relationships • Relationship between precipitating social networks and type of innovative activity/outcome • Role of brokers and intermediaries
Organisation and management of relationships	• Variation of individual-level incentives and motivations across different types of university-industry collaboration • Variation of organisational models and innovation-relevant outputs • Firm strategies for exploiting university knowledge in an open innovation scenario • Impact of institutions on shape, extent and effects of university-industry relationships

Figure 1: Degrees of finalisation in industry-funded research

Research partnerships	Research services
▪ Collaborative (or sponsored) research ▪ University-industry research centres	▪ Contract research ▪ Consulting

low ⟷ high