A review of the literature on university-industry links: towards an integrated approach in the study of influencing factors

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Abstract

There has been growing interest in the study of the role played by university-industry links in the development and strengthening of economic systems. It is consensual that university-industry links play a crucial role in the economy and many studies have examined the factors that influence their occurrence. Two sets of factors can be identified from these studies: demand-side factors (i.e. relating to industry) and supply-side factors (i.e. relating to universities). Most studies covering this topic analyze the influence of demand-side and supply-side factors in isolation. Based on a given set of mechanisms linking university and industry, this paper summarizes the main findings of this literature examining both types of factors in conjunction. This is done for selected advanced and late-industrializing countries. The conclusions examine the emergence of an integrated approach in the analysis of the factors influencing university-industry links.

KEYWORDS: university-industry links, industrial R&D, universities

Word count: 13,269

1 Introduction

It is consensual that the functioning, upgrading and survival of any sophisticated economic system relies upon the exchange of knowledge among its various subsystems and particularly between universities and industry. Based on this consensus, since the 1970s the topic of university-industry links increasingly attracted the attention of policy-makers in both advanced and late-industrializing countries. At the same time, many economists and academics in other social sciences also became interested in this topic and this resulted in a growing body of evidence in these contexts (see OECD, 1990, OECD, 2003, Shin, 2002, Velho, 2005). The goal of this paper is to systematise this body of evidence with respect to the factors that influence the occurrence of university-industry links.

It is commonly understood that the exchange of knowledge between university and industry involves three main mechanisms. First, and perhaps the most common channel, is the training of human resources (OECD, 2001). Faculty in universities usually convert the results of their research to papers, which are systematized in textbooks and teaching programmes. These documents are used in undergraduate and postgraduate training. The most sophisticated forms of training also involve the practice of research. A fraction of all human resources trained in universities such as engineers and scientists are then hired on a contract or permanent basis by industry, where they can apply and make use of the knowledge and skills that they learned in universities. The supply of qualified human resources by universities is a key source of knowledge to industry. Eventually, industry staff may return to the university for short-term training, graduate studies or even permanent posts.

The second channel through which university may exchange knowledge with industry is by means of social networks and informal contacts (Gibbons and Johnston, 1974). In their daily industry practice, engineers and scientists are often challenged by practical problems and questions, which solutions are sometimes beyond the technical and scientific understanding that they already possess. These practical problems and questions may then be informally communicated to their networks of acquaintances in universities. This can be done either purposefully (e.g. via e-mail) or casually (e.g. during a conference). Supposing that the query is relatively trivial then the answer may be obtained in an informal fashion through these social interactions. Otherwise, more elaborate informal queries may trigger research projects with industry participation and eventually result in joint-publications. Still, before the point of formalisation economic incentives tend to be less important in this sort of knowledge exchange.

The third channel through which universities exchange knowledge with industry is via formalized contractual arrangements (OECD, 2002). These formal contracts span across consultancy, research, joint-patenting, technology licensing and the creation of university spin-off companies. At this formalized end, economic incentives gain importance and often technology transfer offices may mediate the relation.

Policy-makers and academics alike share this schematic understanding about the mechanisms forming university-industry links and the related knowledge exchange. This understanding, in itself, is a result of the large amount of attention devoted to the study of university-industry links. In this paper, we use the three mechanisms mentioned above in our analyses: training of human resources, social networks and informal contacts, and contractual arrangements.

While there are validated qualitative and quantitative heuristic tools to measure the occurrence of each of these mechanisms, there is an absence of a deeper and more nuanced view of the evidence informing what are the underlying factors that influence their occurrence. This paper contributes analysis towards an integrated approach to the study of these factors.

In this paper, factors having to do with industry are termed demand-side and factors having to do with universities are termed supply-side. This simplification does not mean that we ignore that the university may sometimes demand knowledge from industry, however it is just one useful way to frame the problem.

In the discussion of these factors, the paper will try and take into account differences in the context in which university-industry links occur in terms of the degree of industrialization of the countries analysed. Hence demand-side factors and supply-side factors are observed in the context of selected cases of both advanced and late-industrializing countries. In this paper, the bulk of discussion on the experiences of advanced countries will be based on the cases of US, Japan, Germany and the UK. The reason for this choice is that these are the largest four economies among advanced countries. Most of the discussion about late-industrializing countries focuses on the main economies of Latin America (Brazil, Argentina, Mexico) and East Asia (particularly South Korea). The reason for this choice of countries is that it may contrast the experience of rapid catching-up in East Asia, with the slower rising of the Latin American countries.

This paper is organized as follows: Section 2 provides a historical background on the relative importance of the mechanisms forming university-industry links, in the contexts of both advanced and the late-industrializing countries, and indentifies which are the key factors influencing university-industry links. Section 3 analyses demand-side factors and section 4 supply-side factors. Section 5 presents the conclusions of the paper.

2. University-industry links: variability in the importance of mechanisms

This section illustrates how the relative importance of the different types of mechanisms forming university-industry links varies in specific circumstances of selected countries. This section discusses the experiences of both advanced (section 2.1) and late-industrializing countries (section 2.2). Based on this discussion, the summary identifies key factors influencing university-industry links.

2.1 Advanced countries

The analysis of university-industry links in advanced countries in this section focuses on the cases of the US, Japan and Germany and the United Kingdom in Western Europe.

Since the 18th century the composition and intensity of the mechanisms linking university and industry in the US have been changing. Three main periods can be identified. First, from the late 18th century throughout the 19th century, the composition of university-industry links was narrow, and the flows of human resources were limited. There is evidence that access to factory staff capable of operating machinery on the shop floor was more important than access to bachelors graduates in some mechanical technologies (OECD, 2001). The contribution of universities to the demand of human resources by industry increased gradually during the 19th century. This occurred particularly in the second half of the century, when engineering teaching and post-graduate education activities became formalised in universities (Mazzoleni, 2003). According to Reich (1985, p.3) at that time industrial R&D was conducted by manufacturing plants. It mainly involved engineering, grading and testing of materials, assaying, quality control and specifications (Mowery and Rosenberg, 1989, p.37). In this context, Etzkowitz (1998) argues that spin-off companies from universities such as Harvard and MIT provided consultancy to industry through contractual arrangements.

Second, from 1900 to the pre-World War II period the importance of human resources flows from universities increased in parallel to that of contractual arrangements. With increases in their size and scale, many firms detached their R&D laboratories from manufacturing plants. As this happened, industry hired not only engineers but also scientists in larger amounts. Such R&D personnel were devoted initially to the application of established knowledge. In some sectors, these changes supported the creation of a knowledge base that prevented the entry of competitors (Mowery and Rosenberg, 1989).

Rosenberg and Nelson (1994) point out that in the early stages of such industries as food, mining, aeronautics, rubber tyres, and paper and pulp there were links to mainly state universities via long-term contractual arrangements. This resulted in part from decentralised nature of the US system, and the attitude of these universities – which actively sought industry funding to complement their financial needs. And it also indicates the importance of geographical proximity in the occurrence of university-industry links.

The intensity of these links increased over time as many of the applied research activities in universities translated into new activities of engineering education. These research activities had direct industry application in specific sectors, e.g., in chemistry and the links between the Universities of Delaware and Illinois and Du Pont. Similarly, in applied chemistry MIT supported Standard Oil in learning about hydrogenation processes (Mowery and Rosenberg, 1998). Social networks and informal contacts pervaded these relations. By the beginning of World War II the most successful R&D laboratories in industry were actively encouraging their personnel to interact with the scientific community in universities and elsewhere (Brooks and Randazzese, 1999).

The third period covers the years since World War II, when all types of mechanisms emerged in the US. While human resources flows towards industry became standard practice, the amount of private investments in university research can be taken as a proxy for variations in the importance of long-term contractual arrangements. According to Brooks and Randazzese (1999), during the 1950s and 1960s, changes in US science policy led to a situation in which the share of industry funding for research in universities was gradually crowded out by public resources. Mowery and Rosenberg (1989, p.259) mention that this share was reduced from about 11% of university research in 1953 to 5.5% in 1960, subsequently declining to 2.7% by 1978 (Brooks and Randazzese, 1999, p.366).

Mowery and Rosenberg (1989) noted that the 1980s was a period in which long-term contractual arrangements regained their importance as a result of policy initiatives. Although secondary to public sources of revenue, industry funding was significant and took a variety of forms including university research centres and by campus-based laboratories. Table 1 illustrates that the participation of business firms funding in US universities' R&D had exceeded 1960 levels by the end of the 1990s (reaching 6.3%). In addition, social networks and informal contacts and contractual arrangements (e.g. in the form of consultancy) were also important (OECD, 2002, p.40). Figures for 2007 indicate that this share has declined slightly to 5.1% (NSF, 2008).

Table 1 Participation of Business Firms in the Funding of University R&D (%), Selected Years

Country-Region/Year	1991	1999	2007[1]
US	5.3	6.3	5.1[2]
Japan	2.4	2.3	2.6[3]
Germany	7.6	11.3	8.7[4]
UK	7.8	7.2	6.5
EU	5.9	6.9	6.4

Notes:
1. Or nearest available year
2. Data estimate.
3. Data for 2003.
4. Germany, UK and EU present rounded figures for 2005.

Sources: Own elaboration based on de Campos (2006), European Commission (2003, 2005 and 2007) and NSF (2008).

The evolution of university-industry links between the second and third periods in the US shows how the relative importance of the different types of mechanisms changed over time. First human resources flows were paramount; subsequently contractual arrangements gained in importance. The key demand-side factors that appear to influence this trend are firm size and scale, while secondary factors were their sector of operation and geographical proximity to universities. In the supply-side, the attitude of universities towards seeking industry funding and their ability to translate findings from research activities into teaching programmes seemed to be paramount.

The case of Japan bears some resemblance with the US. We identified two main periods. First, up to the end of World War II few long-term contractual arrangements were in operation and flows of human resources in terms of scientists were scarce. Freeman (1987) mentions that, with a few exceptions such as Mitsubishi, Japanese corporations were involved in only limited formal R&D. According to Hashimoto (1999), universities were engaged in industry oriented R&D, arguably crowding these activities out of the private sector.

Consultancy provided via contractual arrangements was important during the first period (before 1945). Japan drew on foreign technology in textiles and warfare material and learned to improve it (von Tunzelmann, 1995). These improvements were supported by university researchers (Hashimoto, 1999). The war effort diverted academic research towards military aims. Research groups involving university and industry R&D were formed to tackle specific technological problems. In addition, long-term contractual arrangements became more common. New university departments gained adjunct foundations, which in the post-war years would link them financially to industry with respect to civil technologies. Hashimoto (1999) mentions that this development favoured university-industry links in the post-war period.

The second period was from 1945 to the 1990s when a substantial part of Japan's R&D was aimed at technological scanning. Short-term contractual arrangements continued to be important. For instance, imports to industry were permitted pending clearance by academic engineers (Hashimoto, 1999, p.240). Between 1955 and 1963 there was a substantial increase in university-industry links through the creation of several central research laboratories by firms, in the electrical and chemical industries in particular. Their primary aim was to 'digest' foreign technologies. However, over time their work also included the development of new technologies (Hashimoto, 1999). This organizational change widened the flow of human resources to include scientists. The intensity of these links increased, and a shortage in the supply of engineers emerged (Hane, 1999). In addition, the need for frontier knowledge brought university and industry together; while government established research institutes around strategic industries to reinforce social networks and informal contacts.

In the 1970s Japan underwent a shift in its industry structure towards knowledge intensive sectors. This was aimed at keeping track of dynamic comparative advantages. Japan pursued the development of industries adapted to its resource availability. This increased the flows of human resources, particularly of engineers, into industry (von Tunzelmann, 1995). The practice of reverse engineering forced Japanese industry to reflect upon the whole production process, using the factory as a laboratory. By the mid-1980s this resulted in a further increase in the demand for engineers, and industry began to hire graduates – even physics graduates – to work on the management of manufacturing.

During the 1980s, the diversity of mechanisms forming university-industry links was very wide compared to the immediate postwar period, and included systematic long-term contractual arrangements. Hicks (1992) argued, however, that the level of private investments in Japanese universities' R&D was lower than that in either the US or Western Europe. This resulted partly from the status of universities as public institutions, which had earmarked public funding for their operations (Nezu, 2005). This situation barely changed throughout the 1980s and 1990s (see Table 1 above). In spite of this situation, Hicks provides bibliometric data for the 1980s to show the importance of collaborations between local universities and local firms in terms of paper-based mechanisms. Japanese universities published jointly with local firms more than with foreign companies.

In the 1990s there was an increase in the intensity of these mechanisms, particularly contractual arrangements and joint-publications (Kodama and Suzuki, 2007). Consultancy continued to play an important role in Japan's university-industry links (Hane, 1999, OECD, 2002).

In Japan, the flow of human resources was important in both periods. Even with the increase in contractual arrangements and social networks and informal contacts, the flow of human resources continued to be critical. For instance, there were shortages in the supply of engineers and the absorption by industry of qualified scientists was gradual. A key demand-side factor to explain this trend was the increase in the scale and size of firms. As a result, as Japanese companies increased their formal in-house R&D, universities engaged in more short-term contracting and eventually in long-term contractual arrangements. However, private investments in Japanese university R&D have continued to be more limited than in other advanced countries: in 2003 just 2.6% of university R&D was financed by the private sector (European Commission, 2005).

The experience of Western Europe in university-industry links is country specific. Here, we focus on the cases of Germany and the UK, countries where the variability of university-industry links differed.

One of the factors underlying the industrial leadership of Britain in the 18th century was a culture that praised the application of scientific principles, methods and instruments in technology (Freeman, 2002). At this stage, social networks and informal contacts were quite important, as scientists and industrialists mingled in clubs and societies (von Tunzelmann, 1995). The emphasis was on the application of unexploited knowledge in industry. This knowledge was usually created elsewhere. The country was relatively less involved in the application of frontier knowledge to industry, although early radical scientific contributions emerged in the UK (e.g. Newtonian mechanics). However, towards the late 19th century, flows of human resources into industry were relatively weak. Two related factors explain these trends. First, universities had an elitist attitude, and indeed just two institutions existed (Oxford and Cambridge) until the first quarter of the century (Shinn, 2003). Second, university education received relatively limited public funding (Rose and Rose, 1969).

These trends reflected in relatively limited teaching activities in universities. In terms of the formation of human resources, in the late 19th century the UK had four schools of engineering, it also had 1,600 students in advanced technical areas in 1908. This aspect contrasted with the German case (Albu, 1980).

Germany led several novel industrial sectors later on, into the Second Industrial Revolution (e.g. in chemicals). A key organizational innovation of these sectors was the creation of specialized R&D departments. These departments demanded human resources and knowledge that were met in the late 19th century, and until the First World War, by newer higher-education institutions called Technische Hochschulen. These delivered mass high-quality engineering education activities, associated with doctoral degrees and industrially relevant applied research. By 1908 Germany had 11 of such intuitions (Shinn, 2003). It also had about 10,000 students in advanced technical areas (Albu, 1980).

This evidence compares positively with the more limited UK figures; and makes the point for its problematic and limited supply of human resources to industry. In addition, the UK had a fairly low level of industrial R&D, and had some problems related to intra-firm organization and coordination. This limited its demand for university links. Mowery and Rosenberg (1989) also argued that social networks and informal contacts between university and industry weakened in the decades before World War II. According to these authors, these problems reflected in the limited long-term contractual arrangements that existed. A notable exception was the development of military technologies immediately before and during the war, with the close engagement of academics from Cambridge, Birmingham and other universities with industry participants (Freeman and Soete, 1997).

Before World War II small numbers of graduates characterized the university systems in many Western European countries; however, since the mid 1960s the situation has changed. Universities increasingly embraced teaching activities and the supply of qualified human resources has increased substantially in Europe (Geuna, 1998). The flow of human resources into industry has similarly increased (OECD, 1992). A similar trend can be seen in the amount of private investment in university R&D, which is a proxy for contractual arrangements (Table 1 above).

In terms of funding, in the European Union (EU) data for the period between 1999 and 2005 shows that the private funding of university research has decreased slightly – see Table 1 above. Although university R&D in the EU is primarily publicly funded, by 2005 6.4% was still privately financed. This was higher than the levels for the US and Japan and was partly due to the high level of privately funded university R&D in Germany (over 8% in 2005) (European Commission, 2007). These data confirm the variability in the composition and intensity of university-industry links. In Western Europe, over time, the supply of human resources from universities has become increasingly important, alongside the strengthening of contractual arrangements.

In particular, the contrast between influencing factors becomes clear in the analysis of how Germany caught up with the UK in the beginning of the 20th century. In Germany, in the supply-side new universities delivered industry-oriented teaching and research activities, training relatively large amounts of human resources. These met, in the demand-side, the needs of formalized industry R&D departments in newly emerging industrial sectors. In the UK, in the supply-side, a university system with a more elitist attitude formed a smaller amount of industry-relevant human resources through teaching activities. In the demand-side, industry had a less formalized R&D structure than in Germany.

Thus it can be seen that in the US, Japan and the cases of Germany and UK in Western Europe, once human resources flows stabilized, the relevance of other types of mechanisms increased. Similar to Germany, in Japan and the US contractual arrangements (and social networks and informal contacts) followed the increase in flows of human resource to industry. The next section analyses these developments in the case of late-industrializing countries.

2.2 Late-industrializing countries

This subsection analyses the changes and differences in the composition and intensity of the mechanisms involved in university-industry links in selected late-industrializing countries. The section illuminates differences in the role played by different types of mechanisms across specific countries. The Latin American experience, based on limited human resources flows, is contrasted with the experience of East Asia (particularly South Korea) where these flows were more robust.

During the early 1960s, the main channel involved in university-industry links in Latin America was human resources flows, although they were limited in intensity. The Latin American university system did not train sufficient number of graduates in disciplines, such as engineering, agronomy and veterinary science, with direct application to industry and agriculture (then its most important economic activity) (Ribeiro, 1969).

When human resources became more available in the 1960s and 1970s, the problem of learning how to adapt foreign technology and to generate indigenous technologies continued. Goldemberg (1998) argued that in the post-War period the prevailing approach to innovation was a linear one. Thomas et al. (1996) discuss how such an approach concentrated technological development activities in universities and technology transfer activities in institutes responsible for industry connections. Within this scheme, local industry was protected from competition from imported goods.

García-Guadilla (2000) showed that enrolment in Latin American universities has grown significantly, and distribution across the humanities, social and exact sciences has become more even. However, the application of frontier knowledge from universities to industry has been successful only in certain strategic sectors based on long-term contractual arrangements with state owned companies. Despite the protection afforded by trade barriers, until the 1980s industry tended to be short-termist and reluctant to become involved with more structured internal technological activities, generating limited demand for frontier knowledge (Arocena and Sutz, 2001).

Mexico (Casas et al., 2000), Argentina (Thomas, 1999) and Brazil (Thomas et al., 1996) all display these dynamics. With the failure of the import substitution model to provide sustained growth, and following a period of economic crisis, Brazil and other Latin American economies, in the early 1990s, embarked on liberalization programmes. Casas et al. (2000), Thomas (1999), and Gomes (2001) show that in those countries short-term contractual arrangements increased in intensity.

The Latin American experience contrasts with that of East Asia, and especially South Korea. According to Kim (1995) and Sohn and Kenney (2007) local firms in South Korea have concentrated on absorbing technologies generated elsewhere, in specific sectors such as automotives, electronics and telecommunications. As the Korean economy moved from a closed to an export oriented economy, its industry engaged in more advanced R&D. Local firms progressed from relying on imported technology, to learning about technological adaptation, assimilation and engaging in autonomous improvements. South Korea initially relied on foreign experts in order to undertake technological activities; these experts were subsequently substituted by locally trained engineers and scientists (Sohn and Kenney, 2007, Kim, 1980). While universities have traditionally focused on teaching activities, academic research activities have been undertaken in complementary public research institutes (Hershberg et al., 2007).

The South Korean university system was oriented to supplying large scale human resources (particularly engineers) to industry, a trend followed by Taiwan, Singapore and Hong Kong (Hobday, 1993, Mazzoleni, 2003, Sohn and Kenney, 2007, Wong et al., 2007). More recently, this tendency has extended to post-graduate education across the broader East Asian region. Data for 1999 shows that while China, Taiwan and South Korea were training a quarter to one third of their PhDs in Engineering; in Argentina, Brazil and Mexico this proportion was below 12% (Velho, 2004).

The historical trajectories outlined above have had a major influence on the economies in Latin America and South Korea. Velho (2005) argues that links between universities and private technology-users are weak across Latin America. Kim (2000) and Hershberg et al. (2007) make a similar point about South Korea. These countries are characterized by limited long-term contractual arrangements. Although social networks and informal contacts are becoming more important in South Korea (Sohn and Kenney, 2007), the key difference between the Latin American countries and South Korea is the extent to which universities provide skilled human resources for industry. In addition, the amount of industry funded R&D is limited in Latin America (Table 2).

Table 2 R&D Investment by Source of Funds (%), 1995 to 2005

Sector	Government[1]			Enterprises			HEI[1]		
Country/ Years	1995	2000	2005	1995	2000	2005	1995	2000	2005
Argentina	45.5	70.7	65.3	27.7	23.7	31.0	26.8	5.9	3.7
Brazil	59.1	58.7	58.3	38.2	40.0	39.4	2.7	1.3	2.3
Mexico	66.2	63.0	49.7	17.6	29.5	41.1	16.2	7.5	9.2
Latin America	55.2	60.1	55.4	34.2	34.6	38.0	10.6	5.3	6.6
South Korea	18.8	24.9	25.0	81.2	75.1	75.0	None	None	None

Notes: 1. Higher Education Institutions includes minor sources as non-government organizations and foreign funds.

Sources: Latin American data downloaded from Red de Indicadores de Ciencia y Tecnología -Iberoamericana e Interamericana http://www.ricyt.org/interior/interior.asp?Nivel1=1&Nivel2=2&Idioma= (last accessed 22/10/2008) and South Korean data downloaded from http://www.most.go.kr/most/english/activies_01.jsp (last accessed 24/08/2004) and http://english.mest.go.kr/main.jsp?idx=0402010301 (last accessed 22/10/2008).

In Latin America, the key investor in R&D is the government. This contrasts with South Korea, where the profile of R&D funding is similar to that of the advanced countries. Table 3 shows that in Latin America, an important part of the R&D is performed by government and the higher education institutions. Therefore, there is limited transmission of knowledge embedded in human resources from universities to industry, which contrasts sharply with the situation in South Korea.

Table 3 R&D Investment by Sector of Performance (%), 1995 to 2005

Sector	Government			Enterprises			HEI[1]		
Country/ Years	1995	2000	2005	1995	2000	2005	1995	2000	2005
Argentina[2]	41.0	38.2	39.7	25.9	25.9	32.2	33.1	35.9	28.1
Brazil[3]	12.4	35.1	21.3	42.6	40.1	40.2	45.0	24.8	38.5
Mexico	33.0	41.2	23.4	20.8	29.8	46.5	46.2	29.0	29.6
Latin America	19.8	36.8	23.9	35.9	34.1	39.5	44.3	29.1	36.6
South Korea	18.8	14.7	13.2	73.1	74.0	76.9	8.1	11.3	9.9

Notes: 1. Higher Education Institutions, includes minor participation of non- government organizations.

2. Argentina data for 1996, nearest available year.

3. Brazil data for 2004, nearest available year.

Sources: Red de Indicadores de Ciencia y Tecnología - Iberoamericana e Interamericana http://www.ricyt.org/interior/interior.asp?Nivel1=1&Nivel2=2&Idioma= and http://www.most.go.kr/most/english/activies_01.jsp (last accessed 24/08/2004) and http://english.mest.go.kr/main.jsp?idx=0402010301.

South Korea is an example of a successful case of technological learning, and a clear influencing factor on the supply-side is the relatively large amount of university-trained human resources. This model was adopted by other economies in the East Asian region, e.g. in the cases of Singapore and Taiwan (Wong et al., 2007, Mazzoleni, 2003). Although industry in these countries does not engage in substantial long-term contractual arrangements with universities, they have substantial R&D activities. This appears to be a key demand-side factor in the creation of university-industry links in this context.

This situation contrasts with Latin America. In the supply-side, there is limited training of industrially relevant human resources by universities and links are mainly based on short-term contractual arrangements. A limiting factor in the demand-side appears to be the limited technological learning and related R&D performance.

2.3 The importance of different types of mechanisms and identification of factors influencing university-industry links

Table 4 summarizes the brief accounts in Sections 2.1 and 2.2.

Table 4 Demand-side and supply-side factors influencing university-industry links: phases 1 & 2

Influencing Factors	Phases and mechanisms	
Industry	**Phase 1**	**Phase 2**
Demand-side (section 3) (i) Firm size and R&D formalization (ii) Firm sector (iii) Geographical proximity	Training of human resources	Training of human resources Social networks and informal contacts Formalised contractual arrangements
Universities		
Supply-side (section 4) (iv) Activities (v) Attitudes		

Source: Own elaboration.

The table illustrates that there have been two main phases in the evolution of the different types of mechanisms involved in university-industry links. In phase 1 (corresponding to the early stage of advanced economies and the current stage of late-industrializing countries) the most important mechanism appears to be the flow of human resources from universities. In phase 2, contractual arrangements become more important alongside social networks and informal contacts, while human resources training remain important. This is the current situation in the advanced countries, but has been only partially attained in the late-industrializing countries analysed.

Based on this overall finding, the figure also summarizes the main factors influencing university-industry links identified from the experiences of selected advanced and late-industrializing countries. This underlined the importance of the following factors in the demand-side:

i) firm size and R&D formalization. The discussion made evident that the combination of firm growth in size and scale and the formalization of R&D activities was associated with the transition from phase 1 to phase 2 (for instance in the US and Germany). In late-industrializing countries, the case of South Korea showed how more formalized R&D is associated with substantial university-industry links in phase 1.

ii) firm sector. We identified that specific sectors work in closer relation with universities. For instance, this was the situation in newly formed sectors, e.g. chemicals in Germany in the Second Industrial Revolution. The same occurred in strategic sectors, such as defence in the UK in the period up to the Second World War. In these cases, there was a transition from phase 1 to phase 2.

iii) geographical proximity. The experience of local industries and US state universities is evident. It showed how local industries interacted with these geographically close institutions in the transition between phases 1 and 2.

It also underlined the importance of the following factors in the supply-side:

iv) activities of universities. For instance, in the US and Germany the training of large amounts of qualified engineers and scientists underpinned the transition from phase 1 to phase 2. In the case of East Asia, in phase 1, university-industry links seemed to be more substantial than in Latin America based on the focus of universities on teaching activities.

v) attitudes of universities. The main contrast here is between the proactive attitude of US state universities in industry fund seeking in the context of the transition from phase 1 to phase 2 with the more elitist attitude of British universities.

Factors (i) to (v) will be discussed in greater detail in sections 3 and 4.

3. Demand-side factors influencing university-industry links

This section reviews the evidence of the influence of demand-side factors on university-industry links. The section first analyses the evidence on advanced countries (3.1) and then on late-industrializing countries (3.2).

3.1 Advanced countries

3.1.1 Firm size and R&D formalization

University-industry links have been increasing in advanced countries in recent decades (Mansfield, 1991, Poyago-Theotoky et al., 2002). Yet, evidence from innovation surveys shows that industry managers don not always consider universities as their main source of information for innovation and related R&D activities (Arundel et al., 1995, Cohen et al., 2003, Laursen and Salter, 2003, Hughes et al., 2006). Indeed, just certain types of firms draw directly from universities as a source of information and knowledge.

Firms with different types of R&D activities and different sizes link differently with universities. With respect to R&D activities, a key contribution from Cohen and Levinthal (1990) argued that firms must perform R&D in order to be able to tap into external knowledge, including that from universities. Based on their greater resources, larger firms tend to be able to structure R&D activities and create absorptive capacities better than smaller firms. This is evident from two sets of studies.

First, historical studies focusing on the late 19th century such as Mowery and Rosenberg (1989) and Reich (1985) showed that when US firms increased their scale, they became able to formalize R&D activities in departments dedicated to strategic innovation matters. Freeman and Soete (1997) argued that, as German chemical firms increased in scale, this was accompanied by a structuring of internal R&D activities. In both the US and German cases, these changes increased the intensity and variety of university-industry links.

Second, more recently several survey studies examined issues of firm size. Arundel and Steinmueller (1998) showed that public research (including that performed by universities) is one of the least important sources of information for firms in Europe with less than 500 employees. Arundel and Geuna (2004) found similar results. Arundel and Geuna compared the importance of public research based on a survey of the largest European firms reported by Arundel et al. (1995) and innovative firms in the CIS (Community Innovation Survey). Public research was more important for the large firms reported by Arundel et al. (1995) than for firms in the broader CIS survey sample. In terms of contractual arrangements, Charles and Conway (2001) reported that the bulk (more than 75%) of university income in the UK from short and long-term research contracts came from large firms. In line with these studies, Tether (2002); Bayona et al. (2002), Hoareau and Mohnen (2002), Veugelers and Cassiman (2003); Hughes et al. (2006) all identified that firm size significantly and positively influences the probability of firms in engaging with universities.

To summarize, it could be argued that the relationship between firms' R&D capacity and their size depends in part on the organization of R&D, and its differentiation from ongoing production. As firms have more resources and develop specializations, their knowledge demands move from being concerned only with the operation of technologies, to innovation, which in turn may be related to an increase in the variety and intensity of the mechanisms involved in university-industry links.

3.1.2 Firm sector

Existing studies show that university-industry links are strongly influenced by specific industrial sectors in their early stages. This is partly because the links between science and technology are very close with some of the key scientific contributions to technological development being undertaken in universities when new technologies are emerging.

This was the situation in the case of chemicals and electrical energy in the late 19th century (Freeman and Soete, 1997, von Tunzelmann, 1995, Rosenberg and Nelson, 1994). These sectors drew intensively on human resources flows and contractual arrangements (including consultancy and research). Klevorick et al. (1995) argued that in recent times, the military and biological technologies have sometimes drawn directly on nuclear physics and molecular biology respectively, the bulk of which knowledge originates in universities.

When this early stage has reached maturity, these sectors will absorb knowledge from other sources than universities. Klevorick et al. (1995) argue that as scientific fields become more established, then scientists and engineers in industry have a larger stock of knowledge for tackling more elaborate problems. In addition, learning occurs through feedback from customers and suppliers about the technology (Kline and Rosenberg, 1986, von Hippel, 1988).

Data from innovation surveys in the US have clarified that there is no direct relation between the composition and intensity of university-industry links and features of the sector of operation of companies. For instance, Klevorick et al. (1995) found no direct relation between technological sectors and the type of knowledge involved in specific university-industry links. In their study, it was evident that what they considered high technology sectors (semiconductors, aerospace and agricultural chemicals) were ranked as the principal users of established knowledge. Also higher-tech sectors in their study (e.g. optical instruments and electron tubes) and also lower-tech sectors (e.g. food or animal feed) drew on frontier knowledge.

In this context, drugs were a special case, drawing on both established and frontier knowledge. At the same time, both relatively higher-tech (e.g. industrial organic chemicals, perfumes, cosmetics, toilet preparations) and lower-tech sectors (e.g. motors, generators, industrial controls, motor vehicle parts and accessories, pumps and pumping equipment) rated neither of these forms of scientific knowledge as very relevant to their innovative activities.

In the same vein, Cohen et al. (2003) showed that sectors considered as relatively higher-tech (TV/radio, communication, drugs, semiconductors and related equipment) and lower-tech (oil) appeared as the most significant users of public research (including that from universities). Likewise some sectors considered as high-tech (e.g. electronic equipment) appeared amongst those assigning the smallest importance to these knowledge sources (Cohen et al., 2003).

The lack of a direct relation between the composition and intensity of university-industry links and the industry sector of companies was also suggested by some innovation surveys conducted in Western Europe. According to Arundel et al. (1995) the top four sectors rating public research (including that from universities) as very or extremely important included both higher-tech (pharmaceuticals, aerospace) and lower-tech (food) sectors. Based on the results form the same survey, Arundel and Geuna (2004) indicated that European firms in high-technology sectors put more importance on human resources and social network and informal contacts (e.g. informal contacts and hiring); whilst firms in low-technology sectors rated long-term contractual arrangements and social network and informal contacts (e.g. contract or joint research and conferences) more highly.

In spite of this evidence, the findings with respect to the technological intensity of sectors are still not entirely conclusive. It is possible to identify studies that argue that specific sectors are likely to determine the occurrence of university-industry links. Analyzing the work of Tether (2002); Bayona et al. (2002), Hoareau and Mohnen (2002) Crespi et al. (2005) state that

[…] statistical studies controlling for the industry affiliation of firms shows that firms in high technology sectors have a higher probability of interacting via formal collaboration agreements with universities, and these results are robust across a variety of country settings.

(Crespi et al., 2005, p.6)

The divergence in the findings of these studies lies partly in the definition of high-tech, medium-tech and low-tech because this is still open to discussion and there is no universally accepted definition to these terms.

3.1.3 Geographical proximity

Studies on the geographical proximity of university and industry argue that closeness is a factor that is positively correlated with the occurrence of links (Salter and Martin, 2001). Pavitt (2001) explored this, stating that the importance of university industry proximity for the creation of links results from the relevance of the national science base for innovation. The author showed that small advanced countries, such as the Scandinavian countries, the Netherlands and Switzerland, invest heavily in high-quality academic research, the bulk of which happens inside universities, in order to develop their science bases and to underpin their local industrial structures. Still in the Western European context, Arundel and Geuna (2004) confirmed this statement and found out that the issue of proximity is more relevant for firms with respect to public science sources (including universities) then from alternatives such as suppliers and customers.

A study by Jaffe (1989) explored the issue of geographical proximity empirically. Jaffe analyzed localized knowledge spillovers and identified a positive correlation between R&D expenditures in US universities and corporate patenting activity at state level. This evidence was equated with knowledge spillovers from university to nearby industry. Agrawal and Cockburn (2003) confirmed Jaffe's finding on the close proximity between university and industry R&D at the metropolitan level in US (and Canada).

An important study in the US surveyed the extent to which university R&D was funded by nearby industry (Mansfield and Lee, 1996). The authors analyzed the distance between universities and their industry funding sources (i.e. private R&D laboratories). Considering two distance thresholds (100 and 1,000 miles); they found that firms were more likely to invest in universities geographically closer to them (i.e. within 100 miles). This was interpreted as an advantage for firms establishing links with universities that were closest to them. In terms of the types of knowledge involved, proximity was less important for frontier knowledge but more important for established knowledge. Evidence from Germany confirmed the importance of proximity to universities for human resources flows (Audretsch et al., 2004).

The relationship between geographical proximity and university-industry links is less clear in terms of creation of spin-off firms. Florida (1999) argues that the existence of a linear pathway between the exploitation of university research, to commercial innovation and the creation of local links between universities and spin-off firms is not entirely clear. The Route 128 and Stanford University cases in the US exemplify the successful creation of university spin-off firms (Salter and Martin, 2001). However, these must be considered as quite particular cases. For Japan and Germany, Lehrer and Asakawa (2004) argued that the incidence of spinning-off firms from universities in the biotechnology and internet sectors was heavily influenced by public subsidies.

The empirical evidence suggests that the influence of geographical proximity between university and industry exerts a positive influence on the occurrence of university-industry links. Having identified how the key aspects of demand-side factors influence university-industry links in advanced countries, next we review the evidence about late-industrializing countries.

3.2 Late-industrializing countries

This section analyses the conditions for knowledge demand in late-industrializing countries.

3.2.1 Firm size and R&D formalization

The evidence suggests that the influence of firm size on university-industry links in late-industrializing countries tends to be positive. Innovation surveys show that larger size is related to a higher degree of formalization of R&D activities and in turn to a greater reliance on universities as sources of knowledge. For instance, in Brazil the São Paulo state survey shows that smaller firms rely less on university knowledge. Quadros et al. (2001) show that smaller firms (up to 99 employees) have more limited involvement in innovation and rated universities as less relevant sources of knowledge for innovation activities compared to larger firms and other sources of knowledge.

The results of a survey in Argentina confirm the relation between size and university-industry links. It showed that the smallest firms (up to 25 employees) were less involved in contracts with S&T institutions (including universities) (SECYT, 1999). And across Brazil and Argentina, surveys have shown that other sources of knowledge (e.g. suppliers and customers) are more important than universities.

For South Korea, Kim (2000) argued that over time, as companies increased their R&D expenditures, they formalized the organization of their R&D activities and the number of R&D laboratories increased. Hence, human resources mechanisms became important over time. Kim also argued that university-industry links continued to be problematic in the 1990s, and particularly for mechanisms other than human resources flows. Lee (2002) reported in a survey that smaller firms presented less links with universities than larger firms. In spite of this fact, Hobday et al. (2004) confirmed that even for the largest firms in South Korea, universities are not the main sources of knowledge. The case of South Korea contrasts with Taiwan, Matthews and Hu (2007) reported that larger firms have been increasing their formal links with universities. For instance, this involved not only 'softer' links such as financial donations to universities, but also more elaborate one such as infrastructure support.

The results from these studies indicate that the correlation between firm size, R&D formalization and the occurrence of university-industry links explored in section 3.1.1 for advanced countries is also present in late-industrializing countries. A crucial difference between late-industrializing countries and advanced countries in many sectors is in the nature of the R&D activities performed by companies. Although larger firms in late-industrializing countries are involved in increasingly formalized R&D activities, the nature of these activities has to do more often with technological adaptation and improvements to imported technologies than with either research (basic and applied) or technological development (including original design) (Lall, 1992, Bell and Pavitt, 1995). As a result of the limited research component of their R&D, firms in late-industrializing countries do not need to necessarily get involved in the long-term contractual arrangements that are typical of joint university-industry research activities.

3.2.2 Firm sector

University-industry links in late-industrializing countries often tend to be influenced by the characteristics of the industrial sector involved because some sectors present a higher degree of local-specificity, at least in their early stages.

In Latin America the agriculture and the health sectors can be characterized as local-specific (Velho, 2005). Due to their large natural resources in specific areas such as minerals and forests, some countries have developed long-standing links between university and industry. For instance, in Brazil Suzigan and Albuquerque (2008) identified the cases of iron ore exploration and processing and forest engineering.

However, some sectors involve both local-specificity and strategic issues. This is the case in the defence and energy sectors, where local institutions, including universities, played an important role in technological developments, for instance in Argentina in nuclear energy and weapons (Thomas, 1999) and in Brazil in telecommunications, oil, aerospace and software sectors (Matos, 1999, Marques, 2002, Dagnino and Velho, 1998).

This mix is based on two factors. First, because these sectors are specific to late-industrializing countries, the R&D is usually not available from advanced countries, which triggers technological activities in these late-industrializing countries. Through the performance of these technological activities, links with universities are triggered. Second, the absence of knowledge about these sectors promotes research in the late-industrializing countries. This research initially is performed in universities, with results subsequently being transferred to business firms. This is typical of the agriculture and mining sectors. Pavitt (1998) argues that locally specific sectors contribute to shaping the knowledge base of countries because this knowledge base is dictated by societal needs which are idiosyncratic to every country.

Some authors have argued against local-specificity, claiming that long-term contractual arrangements continue to be unsatisfactory in Latin America because the sub-continent has been specializing in the export and production of mineral and agricultural commodities (Arocena and Sutz, 2001). With regard to the industrial structure in general, even when late-industrializing countries succeed in structuring industries in sectors requiring more elaborate technologies and more structured internal R&D activities, university-industry links may not increase. In the later catching-up stages, firms may continue to source knowledge from foreign sources, with human resources flows between university and industry being more important than short or long-term contractual arrangements. This applies to many leading South Korean firms (Hobday et al., 2004) and the Brazilian aerospace sector (Marques, 2002).

The studies above bring evidence that firms in strategic and locally-specific sectors may forge more robust links with universities.

3.2.3 Geographical proximity

Until recently, very few studies examined whether geographical proximity between university and industry influenced university-industry links in late-industrializing countries (Hershberg et al., 2007). Still, it is possible to identify a general geographical overlap between industrial and university activities.

For instance, in Brazil the bulk of national industry product is concentrated in an urban corridor stretching from the cities of Campinas and São Paulo (in São Paulo state) to Rio de Janeiro. This corridor overlaps geographically with bulk of national production of scientific papers and related training of qualified human resources in major universities. A similar process occurred in South Korea. Until the early 1990s, Seoul accounted for the largest proportion of manufacturing firms in the country and also housed the most prominent university (Seoul National University). This geographic overlap shows that university and industry are closely located and it is plausible that industry benefits from and seek for qualified human resources, but it does not imply necessarily in the existence of other types of university-industry links.

Studies examining specific regions indentify links between local universities and industry. For instance, in South Korea Seoul continues to be prominent, currently housing most of the technology-based firms in the country and a substantial share of the national university system. More robust evidence of links between local universities and industry is also available in the case of electronics in Mexico and Brazil. Figueiredo and Vedovello (2005) and Padilla-Pérez (2008) both show evidence on how the electronics industry in these countries link with universities in the states of Amazonas (in Brazil) and Guadalajara and Jalisco (in Mexico) using mechanisms of various forms and intensity.

While studies similar to those examining the effects of geographical proximity in advanced countries are still rare, academics have paid greater attention to the relationship between geographical proximity and university-industry links in terms of creation of spin-off firms in late-industrializing countries. However, because these studies focus on university-based policy measures, they will be analyzed alongside supply-side factors in the next section (within 4.2 – which covers supply-side factors in late-industrializing countries).

To summarize the empirical evidence on the influence of geographical proximity on university-industry links in late-industrializing countries is less compelling than in advanced countries. Having identified the key aspects of demand-side factors influence university-industry, section 4 now reviews the evidence about supply-side factors.

4. Supply-side factors influencing university-industry links

This section reviews the evidence of the influence of supply-side factors on university-industry links. The section first analyses the evidence on advanced countries (4.1) and then on late-industrializing countries (4.2).

4.1 Advanced countries

4.1.1 University activities

Since their mediaeval origins, universities have undertaken education activities (originally linked to teaching) (Martin, 2003). These activities foster human resources flows and social networks and informal contacts. Engineers and scientists trained in research methods and techniques relevant to industry R&D transfer knowledge to industry via these mechanisms (Pavitt, 2001, Salter and Martin, 2001). Because they provide an effective means of knowledge transfer to industry, education activities are a current concern of advanced countries. Some analysts claim that they are more critical than research, even for the creation of spin-off companies (Audretsch et al., 2004, OECD, 1992).

Universities have also been involved in research from their outset (originally linked to scholarship, which evolved to include the creation of new knowledge) (Martin, 2003).

The orientation and quality of university research activities influence their industry links. In spite of the fact that the distinction between fundamental and applied research is sometimes blurred and manipulated by scientists (Calvert, 2000, Slaughter et al., 2002); with regard to its orientation Cohen et al. (2003) argue that university research that is close to developments in applied areas (i.e. more similar to existing knowledge) tends to be rated by industrial managers as more important than more fundamental university research (i.e. more similar to new knowledge). Likewise, multi-disciplinary university research (or transfer sciences) tends to have more fluid links with industry than disciplinary science (OECD, 1992; Pavitt, 2001). Regardless of the proximity to its application, Pavitt (2001) makes the point that firms tend to use university research that is of high quality.

In addition to education and research, universities have recently been given the role of contributing to the regional economy, known as 'third stream' activity (Etzkowitz and Leydesdorff, 2000). 'Third stream' activities are mainly concerned with the generation, use, application and exploitation of knowledge and other university capabilities outside academic environments. These activities have been also termed 'third mission' (Molas-Gallart et al., 2002).

Third stream activities are usually measured in terms of the eventual intellectual property rights (IPR) and licence revenues from patents, and the number of spin-off companies established, in addition to more mundane sources of revenue such as infra-structure letting (Molas-Gallart et al., 2002, OECD, 2003, Carlsson and Fridh, 2003). Other activities also classified as third stream are advisory work, use of university facilities, non-academic collaboration in academic research, student placements, teaching unrelated to graduate studies, learning activities and non-academic dissemination (Molas-Gallart et al., 2002:50-51). Most third stream activities are focused on spin-off companies and paper-based mechanisms linking university and industry (such as joint-patenting and patent licensing). Crespi et al. (2005) identify that research on the influence of previous experience and the structure of university funding in the undertaking of third stream activities is inconclusive.

Furthermore, the actual outcome of engagement in these activities is not entirely clear. For instance, there has been an increase in university patenting (Florida, 1999, Henderson et al., 1998, Sampat, 2006), although most of these patents are related to a few scientific areas such as biotechnology and electronics, and only a small proportion generate incomes from licences (Carlsson and Fridh, 2003, Geuna and Nesta, 2006). We have also seen in section 3.1.3 that the creation of spin-off companies is a phenomenon related to specific successful cases and not a pervasive occurrence.

It becomes evident that the three types of university activities generate different types of links with universities. These links are more visible in the more traditional teaching and research activities. The emergent third stream activities are associated with new industry links such as joint-patenting and patent licensing, but these seem to be concentrated in a small number sectors and over just a limited number of patents, which generate a high license revenue.

4.1.2 University attitudes

Martin (2003) proposes a classification of universities based on their attitudes to education and research. According to Martin, some universities pursue education to develop the full potential of individuals. In this case research is usually connected to the creation of knowledge ‘for its own sake’. These are classified as ‘classical universities’ (Martin, 2002, Martin, 2003). This attitude was prevalent in the British system in the period from the late 19th century to the early 20th century, and even with the co-existence of polytechnics, it created relatively limited links with industry.

Over time the ‘technical university’ has emerged in Europe, which is concerned with producing trained people with skills useful for society, for instance the École Polytechnique (in France) and Imperial College (in the UK). This model was exported to other continents: e.g. MIT (US) and Tokyo Institute of Technology (Japan) (Martin, 2002, Martin, 2003). These technical universities are more oriented to education and research of societal interest. In this context, Martin also refers to the ‘regional university’, which was created to pursue activities to satisfy regional interests (for instance, the grand écoles in France, the fachhochschulen in Germany and the polytechnics in the UK).

Third stream activities discussed above are related to the concept of an ‘entrepreneurial’ attitude (Clark, 1998). It applies to those institutions seeking funding via the creation of spin-off companies and commercializing of their education and research activities. The ‘entrepreneurial university’ is a concept which is quite close to the ‘regional university’; in principle this ‘entrepreneurial’ attitude generates regional welfare (Clark, 1998, Etzkowitz and Webster, 1998).

To sum up the discussion above, across education, research and third stream activities universities endowed with more ‘technical’, ‘regional’, as well as ‘entrepreneurial’ attitudes should promote better industry links. This should probably hold true across all mechanisms (human resources flows, and short or long-term contractual arrangements). Originally, such attitudes were more common to the German and US experience (and to a lesser extent the Japanese), than the British. More recently, various studies have analysed specific aspects of third stream activities, but the evidence is still too fragmentary (Crespi et al., 2005).

4.2 Late-industrializing countries

4.2.1 University activities

The analysis in this section on the influence of universities’ activities on industry-links in late-industrializing countries draws upon the distinction between education, research and third stream activities mentioned above. Historically the Latin American system was created to educate professional elites (Bernasconi, 2008). Because of this trait, it did not include originally mass tertiary education (Velho, 2004). Teaching activities related to undergraduate training has become more widespread in the region.

In contrast, the East Asian countries started with very limited numbers of qualified human resources, but the large-scale training of engineers was paramount in post-war industrialization processes (Hobday, 1993; Wong et al., 2007). Hence East Asian universities have specialized in human resources flows much more than Latin American ones. Although it is difficult to relate these trends to differences in university-industry links, it could be argued that links based on human resources flows are at the core of the catch-up process in East Asia. This aspect, interdependently coupled with demand side factors as minor shop floor innovations, was seen by Freeman (1992) as crucial in this process.

More recently, East Asian countries have sought a transition from traditional manufacturing to more knowledge intensive sectors in industry (e.g. in Information

Technology) and services. University training evolved to the formation of post-graduates in large-scale, but other types of links between industry and universities are still incipient (Olds, 2007, Sohn and Kenney, 2007). In Latin America, post-graduate training is established just in Brazil, and this is partly reflected in its regional leadership in the increase of scientific publications with reasonable balance between the various disciplines (Bernasconi, 2008, Glänzel et al., 2006).

In terms of research activities, Latin American universities were once more involved with basic research than their East Asian counterparts (Velho, 2004; Hobday, 1993; Kim, 2000). However, recently South Korea has sought to remedy this situation by changing the orientation of its universities activities towards more basic research, and by creating centres for technological development (Kim, 2000). Its universities have tried to engage in more research, and particularly research that is of industrial relevance. Albuquerque (2001) states that this type of research supported the absorption of foreign technology, acting as a 'focusing device' in this process. Meanwhile, Latin American universities have continued to pursue basic research, which often has limited direct industrial relevance (Thomas, 1999).

It is not possible to relate the change in the orientation of East Asian universities' from teaching to research activities to the occurrence of university-industry links. However, Pavitt (2001) argues that university research activities reinforce the supply of skilled labour by serving as a training ground for engineers and scientists, who are prepared to undertake R&D when they move to industry.

Third stream activities have become increasingly popular in both groups of countries. For instance, spin-off companies and patenting have increased in South Korea in recent years (OECD, 2003). Similar developments have occurred in Singapore, particularly with respect of the National University of Singapore, and Taiwan (Wong et al., 2007; Mathews and Hu, 2007). In China universities were once assigned with the mission of creating their own companies in areas where industry-based absorptive capacity was scarce (Eun et al., 2006).

In Latin America, there is also evidence of growing patenting activity in some public universities in Brazil (Etzkowitz et al., 2005). Brazilian universities have systematically pursued incubation activities for university spin-off companies over the past 20 years, having reportedly graduated 1,500 new companies and generated over 30,000 qualified jobs (Anprotec, 2007). Even though, some prominent university spin-off companies are not connected with this trend.

The focus on teaching activities in East Asian universities and the recent related intensification of relevant research activities seems to be coherent with the occurrence of intense flows of trained human resources to industry. This path is less clear in Latin America, with weaker flows of human resources to industry and research that is not always relevant to industry. In both groups of countries third stream activities are quite recent, and results from research are incipient and not conclusive.

4.2.2 University attitudes

Given the set of activities analysed in 4.2.1, a trend can be identified based on the distinction between classical and technical universities. With their emphasis on basic knowledge creation, universities in Latin America have adopted an attitude that is closer to the classical university while the emphasis on training human resources for technological learning in East Asian universities makes them more aligned with the technical university.

It must be noted that despite both groups of countries experiencing an increase in their (largely university-based) share of the world scientific publication; this attitudinal difference does not so far seem to have influenced the limited extent of long-term contractual arrangements (Glänzel et al., 2006; Velho, 2004; Pavitt, 2001).

We have also seen in the previous section that both in Latin America and East Asia universities in some countries embraced an 'entrepreneurial' attitude associated with an increase in third stream activities. Still, and similarly to studies about advanced countries, there is a lack of more in-depth studies about the implications of this process. Issues such as the consequences of these activities over the attitudes and activities of its academic staff, the occurrence of university-industry links and the norms of open science remain areas where more research is needed.

5 Conclusions

The main objective of this paper was to systematize the evidence on the factors that influence the occurrence of university-industry links. The paper analysed factors in the demand-side (i.e. related to industry) and in the supply-side (i.e. related to universities). The paper drew upon historical evidence to indicate trends in the relevance of the mechanisms linking university and industry links. This evidence showed that the training of human resources anticipated the more widespread and intense occurrence of social interactions and informal networks and contractual arrangements.

The paper did not intend to identify an exhaustive list of demand-side and supply-side factors; instead the analysis of the relevance of the different mechanisms linking university and industry underpinned the identification of a set of key influencing factors existing in specific historical contexts. In the demand-side these were: firm size and R&D formalization, firm sector and the geographical proximity between industry and universities. In the supply-side these were related to the activities and attitudes of universities.

The paper then examined what was the influence that these factors exerted on university-industry links. In the demand-side, the evidence suggested a positive influence of firm size and formalization of R&D activities on university-industry links in both advance and late-industrializing countries. The influence of firm sector was more nuanced. In advanced countries, emerging technologies close to the science frontier influence positively the occurrence of university-industry links. In late-industrializing countries this was related to locally-specific and strategic sectors. Lastly, the influence of geographical proximity is more compelling with respect to advanced countries, where closeness is positively related to the occurrence of university-industry links.

In the supply-side, the evidence reviewed suggested that the activities of universities influence their links with industry. In particular, across both advanced and late-industrializing countries these links are more visible for teaching and research than for third stream activities. It is not clear whether this is because third stream activities do not influence the occurrence of university-industry links or because there is not sufficient and conclusive research about this. Likewise, in both groups of countries, certain types of university attitudes seemed to be related to a larger occurrence of university-industry links. In particular, historically universities who embraced a technical attitude (as opposed to a classical attitude) forged closer links with industry.

While it is expected that an entrepreneurial attitude should generate closer links with industry, there is not sufficient empirical evidence to confirm this statement.

Future research might gain substantially from an integration of the influence of both demand-side and supply side factors in the analysis of university-industry links. Few studies such as Mora-Valentin et al. (2004) have attempted to do so. This could clarify, for instance, the understanding of what are the combined characteristics of the universities (in terms of their activities and attitudes) and industries (in terms of their size and R&D activities, sector and geographical distance to universities) that influence the occurrence of specific mechanisms. A limitation of this paper was that it excluded bibliometric studies, the main type of method that takes into account both the demand and the supply-sides. Although they may help in the clarification of some of the issues mentioned, these studies analyse evidence on quite specific mechanisms such as joint university and industry publications and patenting. These are not as pervasive in late-industrializing countries as they are in advanced countries. Furthermore, these studies usually leave aside the three mechanisms focused in this paper: the training of human resources, social networks and informal contacts and contractual arrangements.

Existing conceptual frameworks at the level of innovation systems (Lundvall, 1992), on academic entrepreneurialism (Etzkowitz and Leydesdorff, 2000) and on the labour market for scientists (Lam, 2007) indicate the relevance of this integration. Thus, at a conceptual level there is already recognition of the importance of an integrated approach in the study of university-industry links. However, our review suggested that by and large supply-side and demand-side factors have been analysed in isolation at the empirical level.

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