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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 commonly agreed 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). This paper reviews this literature. It concentrates on the influence of long-term patterns in R&D formalisation on university-industry links. This is done for selected advanced and late-industrialising countries. The literature reviewed indicated that, in advanced countries, university-industry links become more varied as R&D becomes formalised. In late industrialising countries, university-industry links become more intense as R&D becomes formalised.

JEL Classification: O320, O390.

Key words: university-industry links, influencing factors, R&D

1 Introduction

Any sophisticated economic system relies upon the exchange of knowledge between universities and industry. For this reason, the topic of university-industry links has increasingly attracted the attention of policy-makers and academics. This has resulted in a growing body of evidence (e.g. OECD, 1990, OECD, 2003, Shin, 2002, Velho, 2005). The objective of this paper is to systematise this evidence and explore the influence of R&D formalisation on university-industry links.

University-industry links involve three main mechanisms. The first is the training of human resources (OECD, 2001). Faculty in universities use the results of their research to inform teaching and postgraduate training. A fraction of all human resources trained in universities are hired by industry, where they make use of the knowledge and skills learned in universities.

Social networks and informal contacts are the second mechanism (Gibbons and Johnston, 1974). In industry engineers and scientists are challenged by applied problems, which may be communicated to their university networks. Trivial queries are resolved informally. Before the point where elaborate queries may trigger joint-research, economic incentives tend to be less important in this sort of knowledge exchange.

Contractual arrangements are the third mechanism (OECD, 2002). These contracts span across consultancy, joint-research, technology licensing and the creation of spin-off companies. In these cases, economic incentives gain importance and technology transfer offices may mediate the relation.

In this paper, we concentrate on these mechanisms: training of human resources, social networks and informal contacts, and contractual arrangements. This paper will review the literature on the factors that influence their occurrence from the perspective of the characteristics of industry (‘demand-side factors’) and universities (‘supply-side factors’).

On the demand-side, the paper will concentrate on the influence of long-term patterns in R&D formalisation on university-industry links. The paper excluded bibliometric or patenting evidence from its analyses because they are not relevant for the latter factor. The formalisation of R&D involves incremental efforts, and only in advanced stages companies accumulate the capabilities to produce papers and patents. The focus of the paper also precluded the analysis of government policies. The formalisation of R&D is a firm level characteristic, and the review of the literature concentrated on how other characteristics of firms and universities influence their links.

The analyses are based on existing studies and secondary data encompassing advanced and late-industrialising countries. The advanced countries selected are the United States (US), Japan, Germany and the United Kingdom. The late-industrialising countries selection contrasts Latin America (Brazil, Argentina and Mexico) with East Asia (particularly South Korea). These countries have specific trajectories in the formalisation of R&D. This should reflect a variety of patterns that can validate any commonality that emerges.

This paper is organized as follows: section 2 reviews demand-side and supply-side factors influencing university-industry links. Section 3 examines the influence of long-term patterns in R&D formalisation on university-industry links. This evidence is then analysed in section 4. Section 5 presents the conclusions of the paper.

2. Factors influencing university-industry links

2.1 Advanced countries: demand-side

University-industry links have been increasing in advanced countries (Poyago-Theotoky et al., 2002). Still, innovation surveys show that industry managers do not always consider universities as their main source of information for innovation and related R&D (Arundel et al., 1995, Cohen et al., 2003, Laursen and Salter, 2003, Hughes et al., 2006). Firms with specific characteristics use more directly knowledge created by universities.

Link with universities may be different according to firm size and type of R&D. Cohen and Levinthal (1990) claimed that firms must engage in R&D to increase their ability to draw upon external knowledge (e.g. from universities). Larger firms are capable of performing R&D to absorb knowledge partly because they have more resources than smaller firms. Innovation survey shows the capacity of larger firms to link with universities.

Arundel and Steinmueller (1998) showed that public research (including 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. They 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 Community Innovation Survey. Public research was more important for the large firms reported by Arundel et al. (1995) than for firms in the broader Community Innovation Survey. Charles and Conway (2001), Tether (2002), Bayona et al. (2002), Hoareau and Mohnen (2002), Veugelers and Cassiman (2003), Hughes et al. (2006) all identified that larger firm size significantly and positively influences the probability of firms in engaging with universities.

Besides firm size, university-industry links are also strongly influenced by specific industrial sectors in their early stages. This is partly because the links between science and technology are very close 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 on human resources from and contractual arrangements with universities. 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 industries mature technological learning also occurs through feedback from customers and suppliers (Kline and Rosenberg, 1986, von Hippel, 1988).

Innovation surveys in the US have clarified that there is no direct relation between the occurrence 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.

In the same vein, Cohen et al. (2003) showed that sectors considered as relatively higher-tech (telecommunication, drugs and semiconductors) 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. electronics) appeared amongst those assigning the smallest importance to these sources (Cohen et al., 2003). The lack of a direct relation between the occurrence of university-industry links and the industry sector of companies was also suggested by some innovation surveys conducted in Western Europe (Arundel et al. 1995, Arundel and Geuna, 2004).

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 high-tech sectors are likely to determine the occurrence of university-industry links (Tether, 2002, Bayona et al., 2002, Hoareau and Mohnen, 2002).

An alternative set of studies has focused on the geographical proximity of university and industry, and argues 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. Small advanced countries, such as in Scandinavia, 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. Arundel and Geuna (2004) confirmed empirically Pavitt's statement.

A study by Jaffe (1989) analysed 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.

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 analysed the distance between universities and their industry funding sources (i.e. private R&D laboratories). They found that firms were more likely to invest in universities geographically closer to them. 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 for advanced countries shows that: i) larger firms with more resources available for R&D, ii) industries in early stage technologies and iii) firms geographically close to universities are all factors related to the occurrence of university-industry links.

2.2 Late-industrialising countries: demand-side

The influence of firm size on university-industry links in late-industrialising countries tends also to be relevant. Innovation surveys show that larger size is related to a greater reliance on universities as sources of knowledge. In Brazil the São Paulo state survey shows that smaller firms rely less on university knowledge. Quadros et al. (2001) show that firms with 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 knowledge sources.

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

For South Korea, 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. This involved financial donations and infrastructure.

The results from these studies indicate that the correlation between firm size and the occurrence of university-industry links explored for advanced countries is also present in late-industrialising countries. Although larger firms in late-industrialising countries are involved in increasingly formalised R&D, in their early stages these activities have to do with technological adaptation and improvements to imported technologies than with either research or technological development (e.g. original design) (Lall, 1992, Bell and Pavitt, 1995).

University-industry links in late-industrialising 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 characterised 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 university-industry links (for Brazil see Suzigan and Albuquerque, 2008) .

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). Some authors argued against local-specificity, claiming that long-term contractual arrangements continue to be unsatisfactory in Latin America because the sub-continent has been specialising in the production of commodities (Arocena and Sutz, 2001).

With regard to the industrial structure in general, even when late-industrialising 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, e.g. in leading South Korean (Hobday et al., 2004) and Brazilian aerospace firms (Marques, 2002).

Until recently, very few studies examined whether geographical proximity between university and industry influenced university-industry links in late-industrialising 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 domestic industrial output is concentrated in an urban corridor stretching from the cities of São Paulo to Rio de Janeiro. This overlaps with bulk of the domestic output of scientific papers and related training 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 and 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 recruits qualified human resources, but it does not imply in the existence of other 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).

To summarise, the studies above bring evidence that larger firms, and firms in strategic and locally-specific sectors may forge more robust links with universities. The empirical evidence on the influence of geographical proximity on university-industry links in late-industrializing countries is less compelling than in advanced countries.

2.3 Advanced countries: supply-side

This section focuses on two main supply-side factors. These are the activities and attitudes of universities.

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 (Martin, 2003). The orientation and quality of university research activities influence their industry links. The distinction between fundamental and applied research is sometimes blurred and manipulated by scientists (Calvert, 2000, Slaughter et al., 2002); still, with regard to its orientation Cohen et al. (2003) argue that university research that is close to normal advancements to existing knowledge tends to be rated by industrial managers as more important than disruptive university research that creates new knowledge. Likewise, multi-disciplinary university research of good quality has closer links with industry than disciplinary research (OECD, 1992, Pavitt, 2001).

Beyond education and research, universities have recently been given the role of undertaking 'third stream' activities (Etzkowitz and Leydesdorff, 2000). These activities have to do with the creation, application and economic exploration of university-based knowledge by third parties (Molas-Gallart et al., 2002). Indicators such as intellectual property rights, licences and the number of spin-off measure these activities (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 (Molas-Gallart et al., 2002). Most third stream activities are focused on spin-off companies and mechanisms linking university and industry, e.g. joint-patenting and patent licensing.

The results of these activities are 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 license incomes (Carlsson and Fridh, 2003, Geuna and Nesta, 2006).

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, but these seem to be concentrated in a small number of sectors and over just a limited number of patents, which generate high license revenues.

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 training graduates with skills useful for society, for instance Imperial College (United Kingdom). This model was exported to the US (MIT) and Japan (Tokyo Institute of Technology) (Martin, 2002, Martin, 2003). These universities are more oriented to education and research of societal interest. Martin also refers to the 'regional university', which was created to pursue activities to satisfy regional interests (e.g. the land grant colleges in the US and the polytechnics in the UK).

Third stream activities discussed above are related to an 'entrepreneurial' attitude (Clark, 1998). It applies to those institutions seeking funding via the creation of spin-off companies and commercialising 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 summarise, across education, research and third stream activities universities endowed with more ‘technical’, ‘regional’, as well as ‘entrepreneurial’ attitudes should promote better industry links.

2.4 Late-industrialising countries: supply-side

The analysis in this section on the influence of universities on industry-links in late-industrialising countries draws upon the distinction between education, research and third stream activities and the attitudes mentioned above.

Historically the Latin American university system was created to educate professional elites (Bernasconi, 2008). It originally did not include mass tertiary education. Only recently teaching activities related to undergraduate training has become more widespread in the region (Velho, 2004).

East Asian countries started with very limited numbers of qualified human resources, but the large-scale training of engineers was paramount in their industrialisation processes (Hobday, 1993; Wong et al., 2007). Hence East Asian universities have specialised in human resources flows much more than Latin American ones. It can be argued that links based on human resources flows are at the core of the catch-up process in East Asia. This aspect, coupled with demand-side factors as minor shop floor innovations, was seen by Freeman (1992) as crucial in this process.

East Asian countries have recently sought a transition from traditional to knowledge intensive sectors. 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 more established in Brazil, and this is partly reflected in its regional leadership in scientific publications (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 basic research (Kim, 2000). Its universities have tried to engage in more industrially relevant research. Albuquerque (2001) states that this type of research supported the absorption of foreign technology, acting as a ‘focusing device’. Meanwhile, Latin American universities have continued to pursue basic research with limited 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 in East Asia 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 increased 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 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 (e.g. 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). Regarding the attitudes of universities, these studies show that both in Latin America and East Asia universities in some countries embraced an 'entrepreneurial' attitude.

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 human resource links. This path is less clear in Latin America. Based on these patterns, a trend can be identified 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; the attitudinal difference mentioned above does not so far seem to have influenced the limited extent of long-term contractual arrangements in Latin America and East Asia (Glänzel et al., 2006, Velho, 2004, Pavitt, 2001).

The literature review across advanced and late-industrialising countries identified that larger firms in specific sectors forge closer links with universities. The studies reviewed do not relate this to long-term patterns in R&D formalisation. The following question can be posed: what influence does long-term patterns in R&D formalisation exert on university-industry links?

3. University-industry links: the influence of long-term patterns in R&D formalisation

3.1 Advanced countries

Since the 18th century the composition and intensity of the university-industry links in the US have been changing. Three 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 was more important than access to bachelors graduates in mechanical technologies (OECD, 2001). The contribution of universities to the demand of human resources by industry gradually increased 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 engineers and scientists in larger amounts. Such R&D personnel were devoted initially to the application of established knowledge, creating knowledge-based entry-barriers (Mowery and Rosenberg, 1989).

Rosenberg and Nelson (1994) point out that in the early stages of several industries there were links to mainly state universities via long-term contractual arrangements (e.g. mining). This resulted in part from the attitude of these universities – which sought industry funding to complement their financial needs and 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 teaching activities in engineering. These research activities had direct industry application in specific sectors, e.g., in chemistry and the learning about hydrogenation processes (Mowery and Rosenberg, 1998). Social networks and informal contacts pervaded these relations. By the 1930s the most successful R&D laboratories in industry were actively encouraging their personnel to interact with universities (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 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. Industry funding became significant and took a variety of forms including university research centres and campus-based laboratories. The participation of business firms funding in US universities' R&D had exceeded 1960 levels by the end of the 1990s (reaching 6.3% - table 1). In addition, social networks and informal contacts and contractual arrangements (e.g. consultancies) were also important (OECD, 2002, p.40). Figures for 2007 indicate that this share has declined 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]
United Kingdom	7.8	7.2	6.5
European Union	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: de Campos (2006), European Commission (2003, 2005 and 2007) and NSF (2008).

The case of Japan shows 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 exceptions such as Mitsubishi, Japanese corporations were involved in limited formal R&D. According to Hashimoto (1999), universities were engaged in industry oriented R&D.

Consultancy provided via contractual arrangements was important 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 technological problems. Long-term contractual arrangements became more common. New university departments gained foundations, which in the post-war years would link them financially to industry with respect to civil technologies. This development favoured university-industry links in the post-war (Hashimoto, 1999).

From 1945 to the 1990s a substantial part of Japan's R&D aimed at technological scanning. Short-term contractual arrangements continued to be important. Imports to industry were permitted pending clearance by academics (Hashimoto, 1999, p.240). Between 1955 and 1963 there was a substantial increase in university-industry links through the creation of R&D laboratories by firms in the electrical and chemical industries to 'digest' foreign technologies. Over time their work included the development of new technologies (Hashimoto, 1999). This organisational change widened the flow of human resources to include scientists (Hane, 1999). The need for frontier knowledge brought university and industry together; while government established research institutes to reinforce social networks and informal contacts.

In the 1970s Japan privileged knowledge intensive sectors. This increased the flows of human resources, particularly of engineers, into industry (von Tunzelmann, 1995). 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 post war 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 the 1990s there was an increase in the intensity of these mechanisms, particularly contractual arrangements (Kodama and Suzuki, 2007). Consultancy continued to play an important role in Japan's university-industry links (Hane, 1999, OECD, 2002).

The experience of Western Europe is exemplified by the cases of Germany and the United Kingdom. Britain's industrial leadership in the 18th century was underpinned by a culture that praised the application of scientific methods and instruments in technology (Freeman, 2002). Social networks and informal contacts were important then, scientists and industrialists mingled in clubs (von Tunzelmann, 1995). The emphasis was on the application of unexploited knowledge in industry. Towards the late 19th century, flows of human resources into industry were weak because universities had an elitist attitude (just two institutions existed - Oxford and Cambridge) and university education received limited public funding (Rose and Rose, 1969).

These trends reflected in relatively limited teaching activities. In the late 19th century the United Kingdom 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 into the Second Industrial Revolution. An organisational innovation was the formalisation of R&D in dedicated departments. These departments demanded human resources and knowledge links with universities that were met in the late 19th century, and until the First World War, by newer higher-education institutions (*Technische Hochschule*) delivering mass high-quality engineering education, doctoral degrees and applied research. By 1908 Germany had 11 of such intuitions (Shinn, 2003) and about 10,000 technical students (Albu, 1980).

This evidence compares positively with the limited figures in the United Kingdom; and makes the point for its limited supply of human resources. The United Kingdom had a low level of industrial R&D. This limited its demand for university links. Mowery and Rosenberg (1989) argued that social networks and informal contacts between university and industry weakened before World War II. These problems reflected in limited long-term contractual arrangements. An exception was the development of military technologies immediately before and during World War II (Freeman and Soete, 1997).

Before the War small numbers of graduates characterised the university systems in many Western European countries; however, since the mid 1960s the situation has changed. Universities embraced teaching activities and the supply of human resources has increased (Geuna, 1998, OECD, 1992). A similar trend can be seen in the amount of private investment in university R&D, a proxy for contractual arrangements (table 1).

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 (table 1).

By 2005 6.4% of university R&D in the EU was privately financed. This was higher than the levels for the US and Japan and was partly due to Germany (European Commission, 2007).

This review confirms the variability in the composition and intensity of university-industry links. In Germany, US and Japan, over time, the supply of human resources from universities has become increasingly important, alongside the strengthening of contractual arrangements as industrial R&D became formalised.

3.2 Late-industrializing countries

The Latin American experience, based on limited human resources flows and reliance on locally-specific industry sectors, is contrasted with the experience of East Asia (particularly South Korea) where firms pursued more systematic R&D formalisation and these flows were more robust.

During the early 1960s, the main mechanism involved in university-industry links in Latin America was human resources flows. Latin American universities trained limited number of graduates in disciplines, such as engineering, agronomy and veterinary science, with direct economic application (Ribeiro, 1969).

When human resources became more available in the 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 disciplinary distribution 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 originally 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 R&D 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, many Latin American economies, in the early 1990s, embarked on liberalisation programmes. Casas et al. (2000), Thomas (1999), and Gomes (2001) show that in those countries short-term contractual arrangements increased in intensity.

Latin American countries attained robust links with universities in locally-specific and strategic sectors such as mining, agriculture and defence. The R&D for these sectors was usually not available from advanced countries, which triggered indigenous activities. Through the formalisation and performance of these R&D activities, links with universities were triggered. The absence of knowledge about these sectors promoted local research. This research was initially performed in universities, with results being subsequently transferred to business firms and local users of knowledge.

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. As the Korean economy moved from a closed to an export oriented model, its industry engaged in more advanced R&D. Local firms progressed from relying on imported technology supported by foreign experts. The country then moved on to learning about technological adaptation, assimilation and engaging in autonomous improvements. In this process, South Korea substituted foreign experts 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 complement to public research institutes (Hershberg et al., 2007).

Kim (2000) argued that over time, as South Korean companies increased their R&D expenditures, they formalised the organization of their R&D activities and the number of R&D corporate centres increased sharply. These evolved from a single centre in the mid 1960s to over 2,200 centres by the mid 1990s. These centres played a central role in the assimilation of foreign technologies and in strengthening the capacity of local firms to generate new improved and original products. To support this process, the training of human resources 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.

The South Korean university system was oriented to supplying large scale of 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 characterised 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 non-government organizations and foreign funds.

Sources: Latin American data downloaded from Red de Indicadores de Ciencia y Tecnología - Iberoamericana e Interamericana and South Korean data downloaded from MOST.

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.
3. Brazil data for 2004.

Sources: Latin American data downloaded from Red de Indicadores de Ciencia y Tecnología - Iberoamericana e Interamericana and South Korean data downloaded from MOST.

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. An influencing factor in the demand-side appears to be the limited technological learning and related R&D performance.

5 Analysis

Below we propose a framework to classify evidence from the review in the previous sections.

A framework to analyse the influence of long-term patterns in R&D formalisation on university-industry links

Phase **Typical university-industry links**	1 Human resources	2 Idem plus networks & contracts
Demand-side factors	Firm R&D: increasingly formalised	Firm R&D: formalised
Supply-side factors	University activities: centred on teaching	University activities: teaching supported by research

Source: Own elaboration.

The framework suggests that there have been two main phases in the evolution of the different types of mechanisms involved in university-industry links. In phase 1 the most important mechanism is the flow of human resources from universities, with the remaining mechanisms presenting limited relevance. In phase 2, the training of human resources remains important, but social networks and informal contacts alongside contractual arrangements become increasingly salient.

We classify the evidence from the review on section 4 according to this framework. Two trends emerge in the way university-industry links map into phases 1 and 2 in advanced countries.

Firstly, a trend on the demand-side can be informed by the discussion on long-term patterns in R&D formalisation. The discussions on the US and Japan made evident that the formalisation of R&D was associated with the widening of university-industry links. This occurred in the US in the period up to the 1930s and in Japan after World War II. The US trajectory matches the two phases in the framework. The case of Japan matches particularly phase 2. More formalised R&D activities in Germany lead to wider and stronger university-industry links when compared to the UK in the period up to the War. The case of Germany also matches phase 2 of the framework.

Secondly, the discussion also identified the importance of the activities of universities in terms of supply-side factors. In Japan, US and Germany as industry formalised

R&D, the training of large amounts of qualified engineers and scientists supported by relevant university research underpinned the consolidation of phase 2.

In the late-industrialising countries reviewed a consolidation of phase 2 is unclear. One trend is evident in phase 1 from the perspective of long-term patterns in R&D formalisation. The case of South Korea showed how increasingly formalised R&D is associated with substantial university-industry links based on human resources. More limited R&D efforts in Latin America have generated limited university-industry links from the perspective of human resources. On the supply side, in East Asia in general, in phase 1 university-industry links were more substantial than in Latin America based on the focus of universities on teaching activities.

Across both groups of countries it becomes evident from the long-term patterns observed that more formalised R&D activities lead to wider and more intense university-industry links.

6 Conclusions

The paper reviewed the literature that examined how the characteristics of universities and industry influence their links in both advance and late-industrialising countries. In the demand-side, the paper reviewed evidence resulting from the analyses of firm size, industry sector and geographical proximity between universities and industries on university-industry links. In the supply-side, the paper reviewed evidence on the influence of the attitudes and activities of universities on links with industry.

The paper then analysed the influence of long-term patterns in R&D formalisation on university-industry links. The framework in section 5 matched only partially with the cases reviewed, but the evidence showed that university-industry links in advanced countries became more varied as R&D became more formalised.

Across advanced countries university-industry links included substantially all three mechanisms (human resources, social networks and informal contacts and contractual arrangements) after R&D became formalised in the cases of US and Japan. University-industry links were also identified as more varied and intense in the context of Germany than in the UK, where R&D was less formalised. Across late-industrialising countries, university-industry links were identified to be more intense in East Asia, where R&D activities are more substantial, than in Latin America.

There are two limitations to these findings. Firstly, they cover evidence spanning the period between the Second Industrial Revolution and 2005 because the paper focused on long-term patterns. In spite of this choice, the literature on this topic has increased substantially since then and a review of recent trends in university-industry links might inform further the phases in the framework. Secondly, it is beyond the objective of this paper to identity in more detail the transition between the two phases indicated in the framework above. This might be the focus of future research in the area, when the framework may be revisited and improved.

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