# Regions and University-Industry Networks:

# Interactions with Large R&D Performers

**Robert Huggins[1], Hiro Izushi[2] and Daniel Prokop[1]**

[1]Centre for International Competitiveness

Cardiff School of Management

University of Wales Institute, Cardiff

Colchester Avenue, CF23 9XR, UK

Tel: +44 (0) 29 2041 7075

E-mail: rhuggins@uwic.ac.uk

Email: dprokop@uwic.ac.uk

[2] Aston Business School

Aston Triangle

Birmingham, B4 7ET, UK

Tel: +44 (0) 121 204 3324

E-mail: h.izushi@aston.ac.uk

**Paper to be presented at the Regional Studies Association Conference, Pécs, Hungary, May, 2010**

**Abstract**

Universities are increasingly portrayed as knowledge-producing entities that can play a role in providing knowledge for business and industry. Through the use of both social network analysis and regression analysis, the aim of this paper is to analyse the knowledge links between UK universities and large industrial R&D performers located in the UK. We find that those universities with a greater number of links to large R&D-intensive firms have significantly higher levels of research income. Also, firms with a greater number of links to high research income universities invest more in R&D. There is also a strong regional pattern to these knowledge links. Leading research universities in the most competitive regions are better 'placed' to establish links with the relatively high number of industrial R&D performers located in close proximity. These links are important contributors to the research income of universities. However, these networks tend to be concentrated among a small number of elite universities, mainly within the UK's core and most competitive regions, which are also the location for a significant proportion of the UK's most R&D-intensive firms. Networks with large R&D firms in more peripheral regions are less dense, and are not based on the same locational and reputation effects as found in more competitive regions. It is concluded that although much university knowledge transfer policy is based on establishing links with SMEs, it is clear that links with the 'big ticket' large R&D performers are closely connected with university research performance.

**Introduction**

Universities are increasingly portrayed as core knowledge-producing entities that can play an enhanced role in driving innovation and development processes (Cooke, 2004; Fritsch, 2002), acting as key elements of innovation systems, and providing knowledge for business and industry (Foray and Lundvall, 1996; Garlick, 1998; Kitagawa, 2004; Thanki, 1999). In general, network scholars stress that innovation, be it undertaken internally or externally, is a complex process, which may require knowledge flow between firms and other actors (Lichtenthaler, 2005; Meagher and Rogers, 2004). Increasingly, this process is viewed as a systemic undertaking: i.e., firms no longer innovate in isolation but through a complex set of interactions with external actors (Chesbrough, 2003). The rapid growth of research on inter-organisational networks, has led to such networks becoming increasingly recognized as important assets for securing competitive advantage (Dyer and Hatch, 2006; Gulati, 2007; Kogut, 2000; Lavie, 2006; Owen-Smith and Powell, 2004).

External knowledge networks, therefore, are potentially an important aspect of the innovation process. It is through these pipelines that firms procure knowledge that they do not, or cannot, generate internally based on their own capabilities. The knowledge-based view of the firm specifically focuses on knowledge as the key competitive asset of firms, emphasizing the capacity to integrate tacit knowledge, or 'knowing how', as distinct from explicit knowledge, or 'knowing about' (Grant, 1996; Huggins, 2000; Mowery et al., 1998). More and more it is not just the knowledge possessed or created by a firm internally but knowledge from external sources that is regarded as one of the key factors in the innovation process. This practice has been labelled 'open innovation' (Chesbrough, 2003) and is regarded as the hallmark of the most innovative firms. Thus, knowledge networks are a crucial element underlying the economic success and competitiveness of firms (Huggins, 2000; Huggins and Izushi, 2007; Malecki, 2002; Malecki, 2007), with universities viewed as important actors within networks of knowledge-based activities or systems of regional innovation (Cooke et al., 2004; Porter, 1998; Saxenian, 1994).

The aim of this paper is to analyse the knowledge and innovation links between UK universities and large industrial R&D performers located in the UK. Through the use of both social network analysis and regression analysis, we seek to address the following questions: Which types of universities possess the most developed knowledge networks with large industrial R&D players? Which industrial players possess the most developed knowledge networks with the UK higher education sector? Do these links impact on the performance of universities as research institutions? And ,what are the spatial patterns in terms of the regional dimensions of university links with large R&D performers? To achieve this, we utilise data from a unique database containing information on the knowledge-based interactions UK universities have had with external organisations, coupled with data from the UK government's "The 2008 R&D Scoreboard: The Top 850 UK and 1400 Global Companies by R&D Investment". Taken together, these sources facilitate the matching of universities with leading R&D-intensive firms in the UK. Following a review of the substantive literature, we present a social network analysis of the key interactions taking place between universities and these leading firms. We then use regression to examine the extent to which the interactions, along with other related factors – in particular the location of both the universities and firms engaged in these interactions – is related to the capability of universities to raise research income.

**University Knowledge Transfer**

Universities have come to be regarded as key sources of knowledge utilisable in the pursuit of economic growth, with knowledge transfer activities attaining a more important role within universities (Etzkowitz, 2003; Huggins et al., 2008; Lester, 2005). As the role of universities in bolstering knowledge communities and shaping innovation cultures has become more widely recognised, business engagement and innovation capacity have become core themes in university mission statements (Lawton Smith, 2007). These developments have led to notions of \`entrepreneurial universities' (Etzkowitz et al., 2000; Powers, 2004; Slaughter and Leslie, 1997; Smilor et al., 1993) and \`academic entrepreneurs' (Meyer, 2003; Shane, 2004) that are highly involved in venturing and commercialisation activities such as the establishment of spin-off firms, and the exploitation of intellectual property rights through the licensing of technology and patent registration (D'Este and Patel, 2007; Huggins, 2008). Perkmann and Walsh (2007) find that research partnerships between firms and universities are one of the modes of engagement that have the highest impact. Generally, firms with a broader outlook and a greater willingness to collaborate are more likely to engage in university/industry collaboration (Huggins et al., 2008). Larger firms tend to focus on building non-core competences, whereas smaller firms focus on solving problems in their core areas (Santoro and Chakrabarti, 2002). It is argued that the most successful knowledge transferring universities generally possess greater networks with external organizations (Lockett et al., 2003). However, universities are often wary of engaging with a business community dominated by SMEs, which they often regard as inferior and less lucrative collaborators and partners in comparison to larger and more internationally focused and R&D intensive firms (Huggins et al., 2008).

Porter and Ketels (2003) conclude that there is still a lack of understanding in the UK of how to create effective impacts through knowledge transfer from universities, and the role of regions as part of these processes. It is argued that government in the UK has failed to fully realise the significant direct and indirect contribution that the UK's universities make to its local, regional, and national economies (Kelly et al., 2002). On the other hand, it is argued that the performance of many UK universities in the area of knowledge transfer activities has not matched their overall potential, partly due to the relatively low level of internal financial and human resources devoted to such activities (Charles, 2003; Charles and Conway, 2001; Wright et al., 2006). This lack of supply-side resources has been coupled with issues concerning the constraining characteristics of university knowledge transfer.

Despite restrictions and limitations, it is generally acknowledged that universities can serve as sources of knowledge for industry, and that policy initiatives designed to build new niches of knowledge and to develop more effective mechanisms for transferring university-based knowledge to regional partners can potentially bolster regional innovation and economic development (Benneworth and Charles, 2005). Universities have traditionally provided know-how (skills and capability) and know-why (general principles and laws), but the focus on commercialising knowledge, offering consultancy services, and entering into collaborative relationship all demonstrate academic expansion into know-what (facts) and know-who (establishing collaborative relationships) (Charles, 2006). The balance between creating and diffusing knowledge illustrates an emerging `third mission' of universities where new commitments to service complement existing teaching and research missions (Etzkowitz and Zhou, 2006). However, there is significant debate surrounding the extent to which universities should focus on knowledge creation or knowledge diffusion. Scholars such as Feller (2004) argue that universities should focus on building research capacity (knowledge creation) if they want to increase knowledge commercialisation, while others argue that developing more effective mechanisms for transferring knowledge to both private and public sectors (knowledge diffusion) is more important (Stoneman and Diederen, 1994).

**Locational Effects**

A major finding of patent activity studies is that the diffusion of university knowledge spillovers are spatially constrained, i.e. firm innovation is affected by R&D undertaken by universities within the same region (Henderson et al., 1995; Jaffe, 1989). However, studies of knowledge transfer activities based on patent activity are limited in their ability to explain the regional diffusion of university knowledge due to their neglect of other forms of university knowledge other than that protected by patents (Mowery and Sampat, 2004). Generally, university knowledge protected by patents is found to be spatially constrained in regional contexts across both Europe and the US (Fritsch and Varga, 2003), with the knowledge generated within regions playing a role in their economic development. The extent to which university knowledge is spatially constrained is related to the extent to which this knowledge matches the knowledge sought by firms in a respective university's region.

Only those firms and organisations located in a contextual geographic environment rich in relevant knowledge sources can take competitive advantage of the co-location of other knowledge actors. By necessity, leading firms in regionally sparse knowledge environments may be required to make a number of non-local linkages (Malecki and Hospers, 2007). Many firms, therefore, do not acquire their knowledge from within geographically proximate areas, particularly those firms based upon innovation-driven growth where knowledge is primarily sourced internationally (Davenport, 2005). If applicable knowledge is available locally, firms and other institutions will attempt to source and acquire it, if not they will look elsewhere (Kingsley and Malecki, 2004). Also, while firms with low levels of absorptive capacity (Cohen and Levinthal, 1990) tend to network locally, those with higher absorptive capacity are often more connected to global networks (Drejer and Lund Vinding, 2007). This is perhaps to be expected, and illustrates the importance of internal knowledge absorption capacity on external knowledge network development. It also helps explain why SMEs with relatively low knowledge absorption capacities tend to be reliant on more localized networks.

There is a growing school of thought that nonproximate actors are often equally, if not better, able to transfer complex knowledge across such spatial boundaries, providing a high performing network structure is in place (Davenport, 2005; Dunning, 2000; Lissoni, 2001; McEvily and Zaheer, 1999; Palazzo, 2005; Teixeira et al., 2006; Zaheer and Bell, 2005). Therefore, the constraining effect of distance on knowledge flow and transfer is gradually diminishing (Johnson et al., 2006; Tracey and Clark, 2003). This knowledge is often necessarily superior to that available locally, resulting in improved innovation performance. As Singh (2005) finds, simply being in the same locality is often of little benefit for diffusing knowledge from creators to other actors in the locality, with there being a need for networked interaction between these actors. The rise of transnational academic–industry partnerships also demonstrates that neither firms nor universities consider knowledge spillovers to be spatially constrained (Huggins et al., 2008). Despite the recognized importance of proximity to network development, there is an increasing emphasis on the importance of understanding networks and knowledge flows in an environment that is simultaneously local and global (Andersson and Karlsson, 2007; Lorentzen, 2008; Van Geenhuizen, 2008).

**The UK Context**

In many nations there are competitiveness disparities across regions. In the UK this is manifested by the `North-South divide', whereby regions in the southern half of the nation, in particular, London, South East England, and Eastern England are the nation's core economic drivers, while more northern regions suffer from higher unemployment rates and lower income levels (Huggins, 2003; Huggins and Izushi, 2008). Regions such as North East England, Wales, Yorkshire and the Humber, and Northern Ireland are significantly uncompetitive in comparison with their southern neighbours. On the basis of a composite index of competitiveness across the UK's regions, only the three regions of the `Greater South East' are found to be performing above the UK competitiveness average (Huggins, 2003; Huggins and Izushi, 2008).

There are often considerable differences in the capability of universities to effectively transfer their knowledge, and of firms to effectively absorb such knowledge (Huggins, 2008). In general, although there is recognition that universities are potentially key players in achieving economic transformation, the underlying policy perspective is that they are often under-utilized. In the field of higher education, UK policy over the last decade has witnessed a growing alignment between the 'third stream' activities of universities and regional economic development (Charles, 2003; Goddard and Chatterton, 1999; NCIHE, 1997). Indeed, recent years have witnessed a plethora of policy interventions highlighting both national and regional government commitment to science and technology, and the importance of the higher education sector in achieving a step change in the UK's innovation performance by facilitating the growth of the knowledge economy. The last decade has witnessed the transfer of university-generated knowledge taking a stronger role within government policies at a number of levels (Kitson et al., 2009; Lambert, 2003; Sainsbury, 2007; Wellings, 2008).

In general, the utilisation of university knowledge cannot be expected to be uniform, with not all firms or regions benefiting equally. For instance, regions endowed with a higher density of high-technology firms tend to benefit from university knowledge (Audretsch et al., 2005), with there being a significant correlation between the concentration of high-technology industries and university research in high-technology fields within a region (Nagle, 2007).

In the UK a government-sponsored review of the role of universities in stimulating innovation performance argues that, although universities do have a crucial part to play, they cannot be expected to contribute equally to this goal, with the onus firmly placed on `curiosity-driven research' universities as the key sources of innovation (Sainsbury, 2007). Other universities, it is argued, should focus more on economic missions relating to `user-driven research' and professional teaching. The review also highlights the increased prominence of regions as the interface connecting policy makers, universities, and the private sector. Another review sponsored by the government further identifies a need for a better understanding of regional variations in innovation performance and the influence of university research commercialisation and knowledge transfer performance (Wellings, 2008). These reviews both indicate a requirement for policy making to better account for the diversity of universities and the regions in which they are located. Although economic development and innovation policy in the UK have increasingly recognised the need to account for regional diversity, the Further and Higher Education Act of 1992, which established polytechnics as universities, has implicitly pushed an agenda of homogenisation across the higher education sector. Although in itself this has brought many benefits, it has meant that the breadth of differentiated aims and activities across UK institutions has become somewhat opaque from a policy-making perspective.

**Data and Methods**

To construct a sample for this investigation data was collected from three key sources 1) a unique database constructed by the researcher of 9,447 firms and organisations interacting with UK universities between 2005 and 2008 via either Knowledge Transfer Partnerships (KTPs), licensing, patenting, collaborative research, Continuing Professional Development (CPD) courses, or spinout activity; 2) *The 2008 R&D Scoreboard* published jointly by the Department for Innovation, Universities & Skills (DIUS) and the Department for Business, Enterprise & Regulatory Reform (BERR), which consists of two R&D rankings: the *Top 850 UK companies;* and the *Top 1400 Global companies – by R&D investment*, providing a financial data on top R&D firms; 3) HEFCE's (Higher Education Funding Council for England) HE-BCI (Higher Education-Business and Community Interaction) survey data on UK universities and HESA's (Higher Education Statistics Agency) data on university financial accounts.

The unique database was constructed in 2008 by analysed university published research and annual reports, enriched with firm-specific data derived from Financial Analysis Made Ease (FAME) and the collaborative research grant applications databases made available to the researchers by UK's Research Councils. The data collected was limited to a 3-year period of 2005-2008, when interactions were perceived to be either still active or recently completed. Although the UK Research Council data has limitations on research disciplines (D'Este and Patel, 2007), it was used to identify specific locations of firms, and additionally served as a tool to verify data collected from the reports published by universities.

The database listing universities and the firms and organisations with which they interact was used to match universities with top R&D spending firms from *The 2008 R&D Scoreboard*. The result of this effort identified 460 firms with a total R&D expenditure in 2008 higher than £0.9m that had interacted with one or more UK universities between 2005 and 2008. Moreover, from database we used the locations of firms to distinguish the spatial characteristics of interactions. Overall, we have identified a total of 1344 interactions, consisting of 375 where both the firm/plant and university were located in the same region and 969 interactions where firms/plants were located in a different region to the university with which they were interacting. Table 1 presents the data on universities' interactions with firms aggregated to 12 administrative UK regions. The high proportion of university interactions with firms outside their own region suggests a higher tendency towards cross-regional/ national knowledge flows.

Table 1 About Here

The 460 identified firms represent 32 sectors defined by DIUS and BERR. Table 2 illustrates how the identified firms, collaborating with universities, reflect the firms in *Top 1400 Global companies* – by total R&D investment within their sector. The table presents the percentage of the R&D investment in each sector as a percentage of total R&D investment of firms identified as interacting with universities and those ranked on the global list. The representativeness figure is the total R&D investment made by firms in their respective sector identified as interacting with universities as a percentage of the total R&D investment of all firms in that sector listed on the Top 1400 rankings.

Table 2 About Here

The corresponding percentage of the amount of R&D investment by sector for all firms listed on the R&D Rankings and those identified as interacting with universities matches strongly, as shown by Figure 1.

Figure 1 About Here

**Social Network Analysis**

In this paper we construct a network of links between UK universities and R&D intensive firms. The graphical exploration of the network of links between academia and industry representatives allows us to analyse the interactions from a range of different perspectives, which the literature widely refers to as knowledge networks (e.g. Dahl and Pedersen, 2004; Giuliani and Arza, 2009; Huggins et al., 2008; Huggins and Izushi, 2007; Kodama, 2008; Schilling and Phelps, 2007).

We use social network analysis software as a means of graphically representing the interactions between universities and firms. For this purpose we utilise Pajek 1.24 software. Figure 2 depicts how universities interact with firms from a macro perspective in terms of the regional location of universities and the sectoral classification of firms they are interacting with. This analysis makes the concentrations of interactions in the South East, London and East of England from other regions, with universities based in these core regions interacting more frequently with R&D-intensive firms. It is also evident which sectors are most engaged in interactions with universities: pharmaceutical and biotechnology, chemicals, electronic and electrical equipment, technology hardware and equipment, software and computer services, and aerospace and defence.

Figure 2 About Here

Figure 3 presents the network utilising Kamada-Kawai's 'separate components' algorithm. Although the network is visually dense, its network density is only 0.0039. Such a low network density is a result of special character of the network's construct: there are only single directed links between universities and firms, with no direct links between universities and no direct links between businesses. Noticeably, there are 7 separate components consisting of a big network and 6 small networks.

Figure 3 About Here

The components that are not linked with the large network are detailed in Table 3, consisting of 6 universities and 12 firms. It is evident that 5 of these universities are 'new' universities, whilst only one can be classified as 'old.

Table 3 About Here

The reasons for these universities and firms being out of the large network may relate to the specific character of research performed by the universities – very specialist field or research not performed by other universities; firms not having a general high propensity towards interactions with universities in the UK; the interactions of the universities concentrated on SMEs rather than large R&D-intensive firms. In order to establish how well the network is connected, the degree of centralisation is calculated via two variants: outdegree - 0.137; and indegree - 0.044. The results show that universities have a higher degree of centrality than firms in the network, which is to be expected given this network's construct.

By considering the indegree centrality GlaxoSmithKline is identified as having the highest *prestige* in the network, with the highest number of known university interactions. By similar considerations the outdegree centrality finds the University of Cambridge as being the most influential actor in the network. The arithmetic mean of the degree of any vertex in the network is equal to 2.19, meaning that on average each vertex (node) has approximately 2 links. However, as the analysis is concentrated around universities, the arithmetic mean for universities is 11.86, what indicates that on average each university in the network is linked with approximately 12 firms.

By looking at the frequency of the degree of output of the network it can be seen that 7.7% of universities in the network have 33.3% of the links in the network. This third of the links predominately concerns the older and more prestigious universities in the UK. The following are the top linked universities with the most R&D-intensive firms (descending number of links order): University of Cambridge (6.4% of links); Imperial College London (5.9%); University College London (4.2%); Loughborough University (3.9%); University of Bath (3.6%); University of Birmingham (3.3%); University of Manchester (3.2%); and Brunel University (3.1%). The UK core regions are again discernible in the listing above, with 58.3% of the top third of links relating to universities based in core regions. When considering all links, 43.0% of all universities' links with R&D-intensive firms originates from just three regions.

Figure 4 depicts the cohesive subgroup as consisting of a 6-core sub-network (each vertex has at least 6 links, or its degree is 6). This cohesive subgroup is the most interlinked element of the network. Table 4 presents the sub-network. The identified cohesive subgroup consists of those actors most highly involved in knowledge-based interactions with at least 6 different other actors. However, the mix of universities and firms presented in Table 4 does not provide a clear understanding of the impact of these interactions. Therefore, a more explanatory attempt to understand these relationships is provided by the regression analysis in the next section, which will include the observed spatial divide between core and peripheral regions of the UK, as well as distinguishing between 'new' and 'old' university types.

Table 4 and Figure 4 About Here

**Regression Analysis**

The data sources specified above provided the analysis with 13 variables: 1 dependent and 12 independent (Table 5). For the dependent variable, total university research income was chosen as reflecting the research-intensity of universities and their propensity to earn income from their knowledge.

Table 5 About Here

*Dependent variable: University Research Income*

In order to measure the impact of the interactions of universities and R&D-intensive firms we concentrate on university's income generation, based on the assumption that universities with high research income will tend to be more involved in collaborative research with large private sector partners (D'Este and Patel, 2007). Furthermore, it is suggested that universities that generate higher research incomes from external sources tend to produce more innovative outputs (e.g. patents) (Fritsch and Slavtchev, 2007), indicating the benefits of university-industry interaction.

*Independent variables: university internal resources*

It is clearly important to understand how the internal resources of universities affect the dependent variable. Employment measures are often used for the size control of dependent variables (e.g. Coronado et al., 2008; Ronde and Hussler, 2005; Segarra-Blasco and Arauza-Carod, 2008; Tether and Tajar, 2008), and in our case we utilise a university's full-time equivalent (FTE) employment for the same purpose. Another variable that may play a role in explaining university research income generation is the portfolio of active patents, which is a proxy for a university's stock of knowledge that proves to be of commercial value, and the capacity of a university's technology transfer/support office. Furthermore, it is a reasonably reliable measure of innovative output/ activity (Ronde and Hussler, 2005; Tappeiner et al., 2008). Nevertheless it is an imperfect measure as, for example, not all university research is codified into patents and may manifest itself through other forms of knowledge commercialisation (Fritsch and Slavtchev, 2007). To specify university's distinct character, and to an extent, its research or teaching orientation we use a proxy of university type: 'old' – representing traditional universities (including Russell group) – and 'new' – representing the former polytechnics and teaching colleges. This variable assigns a value of '0' to 'new' universities and value '1' to 'old' universities. Finally, the percentage of knowledge transfers in region is used to capture locational character of university–industry interactions, and is measured on a percentage figure basis.

*Independent variables: university knowledge networks*

These explanatory variables are counts of the interactions between universities and the R&D-intensive firms as recorded in the Interaction database. These variables are expected to explain whether a high number of interactions with R&D-intensive industry has an impact on a university research income generation. In order to capture locational differences, the *total* variable is disaggregated into: a) interactions inside a university's region (i.e. a firm and university are both based in the same region), and b) interactions are with firms outside of a university's region (i.e. a firm is based in a different region than university).

*Independent variables: university external environment*

University's location is used to draw the distinction between universities based in core and peripheral regions, as this divide is assumed to capture a wide range of the locational characteristics of economic/business activities. Additionally, as identified from the network analysis, there is a strong concentration of interactions in the core regions, suggesting that universities in 'core' locations may have an advantage in terms of research income generation. The variable construct is based on assigning '1' to those universities that are based in 'core' UK regions (London, South East, and East of England), and number '0' to those universities that are based in 'peripheral' UK regions (South West, Wales, West Midlands, East Midlands, North West, Yorkshire and the Humber, North East, Northern Ireland, and Scotland).

*Independent variables: firm-level innovation input*

By using the number of interactions between universities and firms we hypothesise that there is a relationship between a university's research income generation capability and its frequency/tendency to interact with R&D-intensive businesses. In order to measure the involvement of those businesses in R&D activity and whether highly intensive R&D firms could have a greater impact on university's income generation, we look at their R&D inputs in the form of R&D investment, which is also indicative of absorptive capacity (Tether and Tajar, 2008). There are 4 variables used: 1) representing the aggregated R&D investment of firms linked with university, 2) R&D investment of firms linked with a university and based in the same region and 3) R&D investment of firms linked with university outside a university's region, and 4) the aggregated regional amount of R&D of firms based in each of the 12 regions to control for the size of the R&D in each region potentially available to local universities. These variables are based on the interaction data and are calculated as the sum of the R&D investment of firms that were identified to interact with each specific university. The total R&D of interacting firms in region variable is based on all those interacting firms having branches in the same region as the university.

Table 6 About Here

The relationship between the variables is examined using Pearson's 2-tailed correlations with many variables identified as having a significant relationship (Table 7). All significant correlations with the dependent variable have a positive coefficient. The university's internal resources are found to correlate significantly with university's research income - all except percentage of knowledge transfer within the region. The correlation coefficients are very significant for university's FTE employment and the portfolio of active patents. University network variables are found to correlate significantly with the dependent variable - all having significant association with university income generation. The external environment variable – university location – is not significant nor does it correlate strongly with the dependent variable. The firm's R&D inputs correlate strongly and significantly with university research income, with exception of the total R&D of interacting firms in region variable. The correlation results suggest the significant association of internal resources with university research income generation. Furthermore, such strong associations are also true with regard to university networks and the R&D inputs of R&D-intensive firms.

The identified significant correlations that could have an effect on university's income generation capacity were explored using regression analysis. The chosen estimation method was a robust Generalised Linear Model that deals with outliers in the data as identified via a comparison of models: OLS, Generalised Linear Model, and robust Generalised Linear Model. The robust model proved best at dealing with outliers having a disproportionate influence on estimations. The analysis was performed using SPSS Statistics 17.0.

Table 7 About Here

**Regression Results**

The regression analysis was performed sequentially, as shown in Table 8, starting with a simple model presenting the external environment. In this model (Model 1), all variables enter the equation significantly, with the exception of percentage of knowledge transfers in region. Since the significance levels of university's FTE employment and portfolio of active patents are very high, these variables are retained in the subsequent models. Additionally, the high significance of the portfolio of active patents across all models indicates that university innovation output has a very strong association with university research income generation.

Model 2 explores each university's networks and attempts to explain the locational characteristics of these networks. Only the university interactions in its region variable enters the equation significantly. When interactions with firms are measured by the number of interactions, the number within a university's own region are significant, but not those outside a university's home region.

In Model 3 we concentrate on effects firm's innovation input might have on university's income generation. Noticeably, university interactions outside its region enters the equation significantly, while university's interactions in its region does not. This suggests that the total R&D expenditure of firms interacting with university from outside the university's region tends to reduce university research income generation. In other words, university's income generation increases if university collaborates with outside firms with relatively smaller R&D budgets. This in turn implies the value of interactions with a greater number of firms other than the most R&D-intensive, such as technology-intensive SMEs, rather than universities relying on large corporations and multinationals. Furthermore, if a university interacts with greater number of outside regions firms (i.e. those not covered by DIUS & BERR R&D Scoreboard), its income generation goes up. On the other hand, the total R&D expenditure of firms collaborating with university in university's own region tends to increase university research income generation. The possible interpretations of this effect are: a) a regional effect – the average R&D expenditure of firms is greater in core regions than peripheral regions; if a university is located in proximity to such large R&D-intensive firms, it most likely secures interaction with them; b) a reputation effect – universities highly involved in research with industry attract more interaction with large R&D-intensive firms.

In Model 4 we find that the total R&D expenditure of firms interacting with a university in its own region and the total R&D expenditure of firms interacting with a university in a different region are significant, but university interactions in its region and university interactions outside its region are not. This suggests that the type of firm is more important than the number of interactions. Moreover, the total R&D of interacting firms in region shows a negative association with a university's research income. Its negative sign means that as the rate of a university's share of interactions with firms in a university's region decreases university research income generation declines. In other words, if university is a dominant interactor in its own region, it tends to accrue a larger amount of income most likely from firms outside the region – this resembles a reputation effect.

Table 8 About Here

Furthermore, the percentage of knowledge transfers in region variable shows a negative association with a university's research income and it enters the equation at the 10% level. This suggests that if a university receives a higher proportion of knowledge transfer resources within the region, its research income tends to decrease. Since those firms a university engages with under Knowledge Transfer programmes are often SMEs with low or mid-R&D intensity, it may create a negative image to more R&D-intensive firms.

In Model 4, the university location enters the equation at the 10% level. It should be noted that this happens only when the monopoly effect of a university is accounted for. A possible interpretation could be that in core regions, it is harder to dominate the market for collaboration income as there are more competitors. Thus, even when similar firms are compared between core and peripheral regions, universities in core regions are most likely to show a lower concentration ratio than their counterparts in peripheral regions. On the other hand, universities in core regions most likely enjoy beneficial effects from their location, such as better infrastructure, for example.

Overall, the variables representing a university's capacity for research collaboration – university's FTE employment, portfolio of active patents, and university type – have a close association with university research income generation. Universities in regions where bigger R&D spenders are located take advantage of their location, generating more research income. Furthermore, those universities having a dominant position in their own region appears to create reputation effects, further increasing the amount of research income generated. Finally, it appears that there may be locational effects other than those noted above, which work in favour of universities in core regions, helping them generate a greater amount of research income.

**Discussion**

Although we suggest some caution when interpreting these models, due to the fact they are based only on those interactions made publicly available by universities they nevertheless serve to highlight a number of key trends in terms of the knowledge networks universities use to interact with large industrial R&D performers. These can be best summarised as follows. First, it is clear that these links and networks are important contributors to the research income of universities and, therefore, their overall economic performance. In turn, this performance impacts on the overall economic performance of the region in which particular universities are located.

Second, these networks tend to be concentrated among a small number of elite universities, mainly within the UK's core and most competitive regions, which are also the location for a significant proportion of the UK's most R&D-intensive firms. Although this results in relative competitive regional 'markets' for knowledge-based collaboration, the high density of firms and available R&D ensures that leading universities all engage in a significant number of interactions with these firms, contributing to greater research income performance. Along with these locational effects, leading universities are also subject to beneficial reputation effects, through their engagement with these large and predominantly proximate firms, that heighten their propensity to engage with other large firms outside their own region. These effects also lead to the improved innovation performance of universities as measured for instance, by patent applications and registrations.

Third, and converse to the above, knowledge networks of this kind in more peripheral regions are less competitive and more likely to be dominated by one or two key universities. Regional networks with large R&D firms are necessarily thinner and less dense, and are not based on the same locational and reputation effects. In fact, universities in lagging regions are more likely to engage with smaller less R&D intensive firms, which do not result in the creation of the type of reputation effects that attract larger and more R&D-intensive firms. This reinforces the contention that regional contexts are an important influencing factor not only directly upon universities, but also the impact they are able to exert on the innovative performance of their regions. However, there is also considerable networking variation across different types of universities, and an over-introverted system of interaction may preclude universities from acting as knowledge 'transceivers', receiving knowledge from global sources and transmitting it to more localised actors.

While universities are paying increased attention to commercializing their knowledge, most do not significantly profit from revenue from these activities, and many of the highest yielding revenues come from a limited number of blockbuster inventions. In general, Intellectual Property income across the globe has been highly concentrated among relatively few universities, with technology transfer failing to be financially lucrative for most universities (Powers, 2004). From a policymaking perspective, there is a need to further understand the extent to which current interventions are alleviating market failure or stimulating new channels of knowledge flow resulting in improved economic performance. There are a number of policies that governments pursue when seeking to promote innovation, including policy initiatives to foster the commercialization of university research, encouraging firms to invest in R&D, or encouraging the activities of venture capital funds. As Driver and Oughton (2008) argue, the important task for public policy is to characterize accurately the 'interplay of causal factors in innovation expenditure', although 'identifying the nature of what is required (or how to intervene) is methodologically difficult'. A key issue in less competitive regions appears to be the lack of an appropriate critical mass of nodes in regional knowledge and innovation systems.

In general, the diversity of university types is not sufficiently recognised by policy makers, and also that such diversity means that the role of universities is likely to vary on an institution-by-institution basis (Abreu et al., 2008; Kitson et al., 2009; Lawton Smith, 2007). Although some universities are relatively weak economic and innovation performers on a national scale, at a regional level they play a vital role as the providers of both wealth and innovation capacity (Huggins and Johnston, 2009). The regional environment may also influence the actions of institutions. For instance, a relatively strong knowledge-generating university in a relatively weak region may have a greater propensity to engage with firms in other regions. Weak regions may be characterised by insufficient private sector economic activity and a higher-than-average density of small firms perceiving little benefit to be gained from engaging with the higher education sector. In the long term this may result in a leakage of knowledge from the home region serving only to exacerbate regional competitiveness differentials (Siegel et al., 2007).

One of the key differences identified in the approaches adopted in the knowledge transfer strategies is based on the economic and institutional conditions in each region. Leading regions for innovation are often those with multiple nodes of research strength including universities, government laboratories, non-profit research organizations, and private-sector R&D units, while in lagging regions there is often only a single dominant university and a lack of other kinds of research and industrial partners with advanced capabilities with whom the university can interact (Youtie and Shapira, 2008). Even if universities improve their knowledge transfer efforts, the impact on regional development is unclear, since apparent demand from regional business communities to interact and make use of the knowledge base of the higher education sector is often weak, although the level of latent demand may be significantly higher. While the potential of universities and their knowledge can be further harnessed to catalyse new regional knowledge-based economic activity, it is unlikely they can achieve this alone. The onus being placed on universities to become the bases of commercializable knowledge in many regions is probably too heavy. A cursory analysis of leading regions from around the world indicates that while universities can play an important role, they are often supported by a system of publicly-funded research institutes and laboratories dedicated to applied research, much of which has transfer potential.

From a university perspective, it should be noted that networks in knowledge-intensive sectors and markets tend to be highly heterogeneous, requiring additional network management resources, in order to convey complex ideas across these markets and their audiences (Darr and Talmud, 2003; Gibbons et al., 1994; Reagans and McEvily, 2003). Many universities may lack the requisite number of knowledge brokers and gatekeepers to enable and moderate the flow of knowledge both into and from each institution and translate this into terms that are meaningful within the institution as well as to other network members as appropriate (Harada, 2003; Tushman and Katz, 1980). As Zaheer and Bell (2005) note, there is a requirement to focus on the dual necessity of forming and managing external contact networks that produce value, as well as possessing the internal capabilities to profitably exploit this knowledge.

## Conclusion

This paper has found there to be significant knowledge links between leading research-intensive universities and leading industrial R&D performers in the UK, with 'research rich' universities tending to be more networked and outward looking. These links potentially benefit both players through a greater capacity to innovate and commercialise knowledge. Many of the resources associated with successful knowledge-based interaction are skewed towards the larger and more prestigious universities, highlighting the existence of a large knowledge network divide across the higher education sector. Those universities with a greater number of links to large R&D-intensive firms have significantly higher levels of research income compared to those with less links. Also, those firms with the greater number of links to high research income universities invest more in R&D. There is also a strong regional pattern to these knowledge links. Leading research universities in the Greater South East – covering the most competitive and prosperous regions of the UK - are better 'placed' to establish links with the relatively high number of industrial R&D performers located in close proximity, i.e. within the same region. Although knowledge transfer activity is a source of advantage for universities, markets for knowledge in less competitive regions appear to possess demand-side weaknesses.

Universities in less competitive regions do not have the same density of R&D performers in close proximity, with which they can potentially forge links. Universities in less competitive regions, therefore, may be 'forced' to cultivate links with R&D performers based at a relative distance to their own location. Furthermore, less competitive regions are generally compromised by universities that are less research intensive, on the whole, and less linked to industrial knowledge bases than their more competitive counterparts. Although much university knowledge transfer policy is based on establishing links with SMEs, it is clear that links with the 'big ticket' large R&D performers are closely connected with university performance. Therefore, there is a clear need to better articulate policies aimed at improving the knowledge bases of relatively lagging regions. Clearly, the movement of knowledge infrastructure across regions is not a feasible option. This suggests that better connecting knowledge bases across regions may provide a more realistic option. Finally, the most important role of universities will continue to be their human capital creation capacities and ability to produce highly skilled and employable new labour market entrants in the form of their graduates.

**Acknowledgements**

We are grateful to the Economic and Social Research Council (Grant Award Reference: RES-171-25-0023) for funding the research upon which this paper is based. The usual disclaimers apply.

**References**

Abreu, M., Grinevich V., Hughes, A., Kitson, M., Ternouth, P., 2008. Universities, Business and Knowledge Exchange. The Council for Industry and Higher Education, London.

Andersson, M., Karlsson, C., 2007. Knowledge in regional economic growth: The role of knowledge accessibility. Industry and Innovation 14, 129-149.

Audretsch, D.B., Lehmann, E.E., Warning, S., 2005. University spillovers and new firm location. Research Policy 34, 1113-1122.

Benneworth, P., Charles, D., 2005. University spin-off policies and economic development in less successful regions: Learning from two decades of policy practice. European Planning Studies 13, 537-557.

Charles, D., 2003. Universities and territorial development: Reshaping the regional role of UK universities. Local Economy 18, 7–20.

Charles, D., 2006. Universities as key knowledge infrastructures in Regional Innovation Systems. Innovation 19, 7-20.

Charles, D., Conway, C., 2001. Higher Education Business Interaction Survey. Higher Education Funding Council for England, Bristol.

Chesbrough, H., 2003. Open Innovation: The New Imperative for Creating and Profiting from Technology. Harvard Business School Press, Boston, MA.

Cohen, W.M., Levinthal, D.A., 1990. Absorptive capacity: A new perspective on learning and innovation. Administrative Science Quarterly 35, 128-152.

Cooke, P., 2004. Regional innovation systems - an evolutionary approach, in: Cooke, P., Heidenreich, M., Braczyk, H. (Eds), Regional Innovation Systems: The Role of Governance in a Globalised World. Routledge, London, pp. 1-18.

Cooke, P., Heidenreich, M., Braczyk, H., 2004. Regional Innovation Systems: The Role of Governance in a Globalised World, Routledge, London.

Coronado, D., Acosta, M., Fernández, A., 2008. Attitudes to innovation in peripheral economic regions. Research Policy 37, 1009-1021.

D'Este, P., Patel, P., 2007. University – industry linkages in the UK: What are the factors underlying the variety of interactions with industry? Research Policy 36, 1295-1313.

Dahl, M.S., Pedersen, C.Ø.R., 2004. Knowledge flows through informal contacts in industrial clusters: myth or reality? Research Policy 33, 1673-1686.

Darr, A., Talmud, I., 2003. The structure of knowledge and seller-buyer networks in markets for emergent technologies. Organization Studies 24, 443–461.

Davenport, S., 2005. Exploring the role of proximity in SME knowledge-acquisition. Research Policy 34, 683-701.

Drejer, I., Lund Vinding, A., 2007. Searching near and far: Determinants of innovative firms' propensity to collaborate across geographical distance. Industry and Innovation 14, 259-275.

Driver, C., Oughton, C., 2008. Dynamic models of regional innovation: Explorations with British time-series data. Cambridge Journal of Regions, Economy and Society 1, 205-217.

Dunning, J.H., 2000. Regions, globalization, and the knowledge economy: The issues stated, in: Dunning, J.H. (Ed.), Regions, Globalization, and the Knowledge-Based Economy. Oxford University Press, Oxford, pp. 7-41.

Dyer, J.H., Hatch, N.W., 2006. Relation-specific capabilities and barriers to knowledge transfer: Creating advantage through network relationships. Strategic Management Journal 27, 701–719.

Etzkowitz, H., 2003. Innovation in innovation: the triple helix of university-industry-government relations. Social Science Information 42, 293–337.

Etzkowitz, H., Webster, A., Gebhardt, C., Regina, B., Terra, C., 2000. The future of the university and the university of the future: evolution of ivory tower to entrepreneurial paradigm. Research Policy 29, 313-330.

Etzkowitz, H., Zhou, C., 2006. Triple helix twins: innovation and sustainability. Science and Public Policy 33, 77-83.

Feller, I., 2004. Virtuous and vicious cycles in the contributions of public research universities to state economic development objectives. Economic Development Quarterly 18, 138–150.

Foray, D., Lundvall, B., 1996. OECD, 1996. The knowledge-based economy: from the economics of knowledge to the learning economy, in: OECD (Eds.), Employment and Growth in the Knowledge-Based Economy. OECD, Paris, pp. 3–28.

Fritsch, M., 2002. Measuring the quality of regional innovation systems: A knowledge production function approach. International Regional Science Review 25, 86-101.

Fritsch, M., Slavtchev, V., 2007. Universities and Innovation in Space. Industry and Innovation 14 (2), 201-218.

Fritsch, M., Varga, A., 2003. Spatial knowledge spillovers and university research: evidence from Austria. Annals of Regional Science 37, 303–322.

Garlick, S., 1998. Creative Associations in Special Places: Enhancing the Role of Universities in Building Competitive Regional Economies. Deetya, Canberra.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P,. Trow, M., 1994. The New Production of Knowledge. SAGE Publications, London.

Giuliani, E., Arza, V., 2009. What drives the formation of 'valuable' university-industry linkages?: Insights from the wine industry. Research Policy 38, 906-921.

Goddard, J., Chatterton, P., 1999. Regional Development Agencies and the Knowledge Economy: Harnessing the potential of universities. Environment and Planning C 17, 685-699.

Grant, R., 1996. Towards a knowledge based theory of the firm. Strategic Management Journal 17, 109–122.

Gulati, R., 2007. Managing Network Resources: Alliances, Affiliations, and Other Relational Assets. Oxford University Press, Oxford.

Harada, T., 2003. Three steps in knowledge communication: the emergence of knowledge transformers. Research Policy 32, 1737–1751.

Henderson, J. V., Kuncoro, A. and Turner, M. (1995) Industrial development in cities. Journal of Political Economy 103, 1067–1090.

Huggins, R., 2000. The Business of Networks: Inter-Firm Interaction, Institutional Policy and the TEC Experiment. Ashgate, Aldershot.

Huggins, R., 2003. Creating a UK competitiveness index: regional and local benchmarking. Regional Studies 37, 89-96.

Huggins, R., 2008. Universities and knowledge-based venturing: Finance, management and networks in London. Entrepreneurship and Regional Development 20, 185–206.

Huggins, R., Izushi, H., 2007. Competing for Knowledge: Creating, Connecting and Growing. Routledge, London.

Huggins, R., Izushi, H., 2008. UK Competitiveness Index 2008. Centre for International Competitiveness, University of Wales Institute, Cardiff.

Huggins, R., Johnston, A., 2009. The economic and innovation contribution of universities: A regional perspective, Environment and Planning C: Government and Policy 27, 1088-1106.

Huggins, R., Johnston, A., Steffenson, R., 2008. Universities, knowledge networks and regional policy. Cambridge Journal of Regions, Economy and Society 1 (2), 321-340.

Jaffe, A.B., 1989. Real effects of academic research. American Economic Review 79, 957–970.

Johnson, D.K.N., Siripong, A., Brown, A.S., 2006. The demise of distance? The declining role of physical proximity for knowledge transmission. Growth and Change 37, 19–33.

Kelly, U., Marsh, R., McNicoll, I., 2002. The Impact of Higher Education Institutions on the UK Economy. Universities UK, London.

Kingsley, G., Malecki, E.J., 2004. Networking for competitiveness. Small Business Economics 23, 71-84.

Kitagawa, F., 2004. Universities and regional advantage: Higher education and innovation policies in English regions. European Planning Studies 12, 835–852.

Kitson, M., Howells, J., Braham, R., Westlake, S., 2009. The Connected University: Driving Recovery and Growth in the UK Economy. NESTA, London.

Kodama, T., 2008. The role of intermediation and absorptive capacity in facilitating university-industry linkages – An empirical study of TAMA in Japan. Research Policy 37, 1224-1240.

Kogut, B., 2000. The network as knowledge: generative rules and the emergence of structure. Strategic Management Journal 21, 405–425.

Lambert, R., 2003. Lambert Review of Business University Collaboration. HMSO, Norwich.

Lavie, D., 2006. The competitive advantage of interconnected firm: An expansion of the resource-based view. Academy of Management Review 31, 638–658.

Lawton Smith, H., 2007. Universities, innovation, and territorial development: A review of the evidence. Environment and Planning C: Government and Policy 25, 98-114.

Lester, R.K., 2005. Universities, innovation, and the competitiveness of local economies: summary report from the local innovation systems projectöphase I. WP 05-010, Industrial Performance

Center, Massachusetts Institute of Technology, MA. Available at: http://web.mit.edu/ipc/publications/pdf/05-010.pdf

Lichtenthaler, U., 2005. External commercialization of knowledge: Review and research agenda. International Journal of Management Reviews 7, 231-255.

Lissoni, F., 2001. Knowledge codification and the geography of innovation: The case of Brescia mechanical cluster. Research Policy 30, 1479-1500.

Lockett, A., Wright, M., Franklin, S., 2003. Technology transfer and universities' spin-out strategies. Small Business Economics 20, 185–200.

Lorentzen, A., 2008. Knowledge networks in local and global space. Entrepreneurship & Regional Development 20, 533-545.

Malecki, E.J., 2002. Hard and soft networks for urban competitiveness. Urban Studies 39, 929–948.

Malecki, E.J., 2007. Cities and regions competing in the global economy: Knowledge and local development policies. Environment and Planning C: Government and Policy 25, 638-654.

Malecki, E.J., Hospers, G.-J., 2007. Knowledge and the competitiveness of places, in: Rutten, R., Boekema, F. (Eds.), The Learning Region: Foundations, State of the Art, Future. Edward Elgar, Cheltenham, pp. 143-159.

McEvily, B., Zaheer, A., 1999. Bridging ties: A source of firm heterogeneity in competitive capabilities. Strategic Management Journal 20, 1133-1156.

Meagher, K., Rogers, M., 2004. Network density and R&D spillovers. Journal of Economic Behavior and Organization 53, 237-260.

Meyer, M., 2003. Academic entrepreneurs or entrepreneurial academics? Research-based ventures and public support mechanisms. R&D Management, 33: 107–115.

Mowery, D., Sampat, B., 2004. The Bayh-Dole Act of 1980 and University–industry technology transfer: a model for other OECD governments? Journal of Technology Transfer 30, 115–127.

Mowery, D.C., Oxley, J.E., Silverman, B.S., 1998. Technological overlap and interfirm cooperation: implications for the resource-based view of the firm. Research Policy 27, 507–523.

Nagle, M., 2007. Canonical analysis of university presence and industrial comparative advantage. Economic Development Quarterly 21, 325–338.

NCIHE, 1997. Higher Education in the Learning Society: Report of the National Committee. HMSO, London.

Owen-Smith, J., Powell, W.W., 2004. Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. Organization Science 15, 5-21.

Palazzo, G., 2005. Postnational constellations of innovativeness: A cosmopolitan approach. Technology Analysis & Strategic Management 17, 55–72.

Perkmann, M., Walsh, K., 2007. University-industry relationships and open innovation: towards a research agenda. International Journal of Management Reviews 9, 259–280.

Porter, M., 1998. Clusters and competition: new agendas for companies, governments and institutions, in: Porter, M., (Ed.), On Competition. HBS Press, Boston, MA.

Porter, M.E., Ketels, C.H.M., 2003. UK Competitiveness: Moving to the Next Stage. Department of Trade and Industry, London.

Powers, J.B., 2004. R&D funding sources and university technology transfer: What is stimulating universities to be more entrepreneurial? Research in Higher Education 45, 1–23.

Reagans, R., McEvily, B., 2003. Network structure and knowledge transfer: the effects of cohesion and range. Administrative Science Quarterly 48, 240–267.

Rondé, P., Hussler, C., 2005. Innovation in regions: What does really matter? Research Policy (34), 1150-1172.

Sainsbury, D., 2007. The Race to the Top: A Review of Government's Science and Innovation Policies. HMSO, London.

Santoro, M.D., Chakrabarti, A.K., 2002. Firm size and technology centrality in industry-university interactions. Research Policy 31, 163–1180.

Saxenian, A., 1994. Regional advantage: culture and competition in Silicon Valley and Route 128. Harvard University Press, Cambridge, MA.

Schilling, M.A., Phelps, C.C., 2007. Interfirm Collaboration Networks: The Impact of Large-Scale Network Structure on Firm Innovation. Management Science 53 (7), 1113-1126.

Segarra-Blasco, A., Arauzo-Carod, J.-M., 2008. Sources of innovation and industry-university interaction: Evidence from Spanish firms. Research Policy 37, 1283-1295.

Shane, S., 2004. Academic Entrepreneurship: University Spinoffs and Wealth Creation. Edward Elgar, Cheltenham, UK.

Siegel, D., Wright, M., Lockett, A., 2007. The rise of entrepreneurial activity at universities: organizational and societal implications. Industrial and Corporate Change 16, 489-504.

Singh, J., 2005. Collaborative networks as determinants of knowledge diffusion patterns. Management Science 51, 756–770.

Slaughter, S., Leslie, L.L., 1997. Academic Capitalism: Politics, Policies, and the Entrepreneurial University. Johns Hopkins University Press, Baltimore, MD.

Smilor, R.W., Dietrich, G.B., Gibson, D.V. 1993. The entrepreneurial university: the role of higher education in the United States in technology commercialization and economic development. International Social Science Journal 135, 1–11.

Stoneman, P., Diederen, P., 1994. Technology diffusion and public policy. The Economic Journal 104, 918–930.

Tappeiner, G., Hauser, C., Walde, J., 2008. Regional knowledge spillovers: Fact or artifact? Research Policy 37, 861-874.

Teixeira, A., Santos, P., Oliveira Brochado, A., 2006. Does proximity really matter in international R&D cooperative projects? Paper presented at European Network on Industrial Policy (EUNIP) 9th International Conference, Limerick, Ireland, 20-22 June 2006.

Tether, B.S., Tajar, A., 2008. Beyond industry-university links: Sourcing knowledge for innovation from consultants, private research organisations and the public science-base. Research Policy 37, 1079-1095.

Thanki, R., 1999. How do we know the value of higher education to regional development? Regional Studies 33, 84–89.

Tracey, P., Clark, G.L., 2003. Alliances, networks and competitive strategy: rethinking clusters of innovation. Growth and Change 34, 1–16.

Tushman, M.L., Katz, R., 1980. External communication and project performance: an investigation into the role of gatekeepers. Management Science 26, 1071–1085.

Van Geenhuizen, M., 2008. Knowledge networks of young innovators in the urban economy: Biotechnology as a case study. Entrepreneurship & Regional Development 20, 161-183.

Wellings, P., 2008. Intellectual Property and Research Benefits. Lancaster University, Lancaster.

Wright, M., Lockett, A., Clarysse, B., Binks, M., 2006. University spin-out companies and venture capital. Research Policy 35, 481–501.

Youtie, J., Shapira, P., 2008. Building an innovation hub: A case study of the transformation of university roles in regional technological and economic development. Research Policy 37, 1188-1204.

Zaheer, A., Bell, G., 2005. Benefiting from network position: Firm capabilities, structural holes, and performance. Strategic Management Journal 26, 809–825.

Table 1: Number of Identified Interactions Between Universities and R&D-Intensive Firms

| **Region (universities)** | **Same Region Interactions** | **Different Regions Interactions** |
|---|---|---|
| East Midlands (9) | 13 | 104 |
| East of England (9) | 39 | 115 |
| London (39) | 96 | 202 |
| North East (5) | 5 | 28 |
| Northern Ireland (2) | 4 | 14 |
| North West (14) | 37 | 80 |
| Scotland (15) | 35 | 81 |
| South East (17) | 59 | 80 |
| South West (13) | 31 | 80 |
| Wales (12) | 8 | 42 |
| West Midlands (12) | 35 | 77 |
| Yorkshire and the Humber (11) | 13 | 66 |

*Source:* DIUS and BERR, own elaboration

Table 2: Breakdown of R&D Investment by Sector

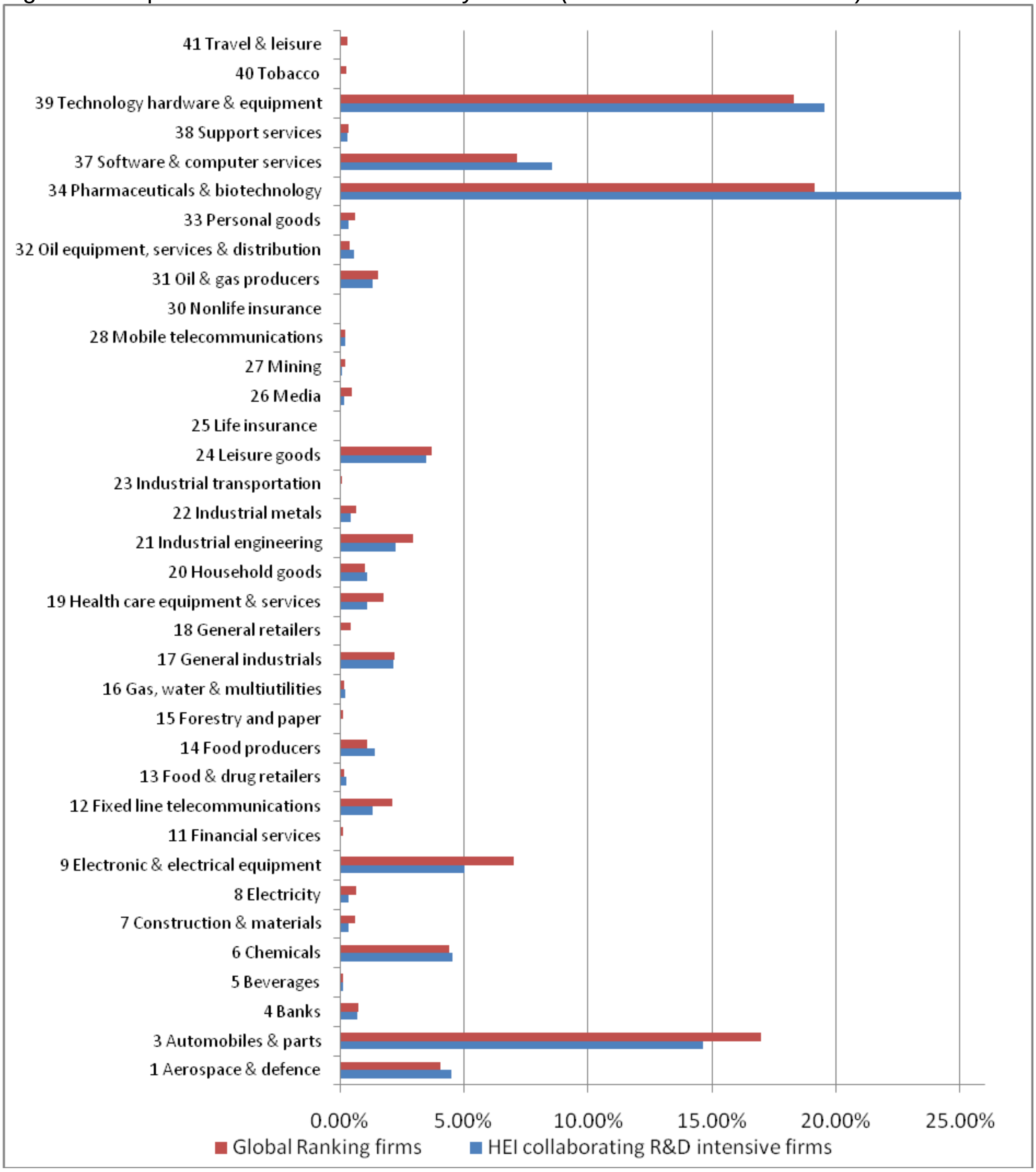
| Sectors | Firms interacting with universities | All listed on the Top 1400 Global Rankings | Representativeness[1] |
|---|---|---|---|
| **1 Aerospace & defence** | 4.48% | 4.05% | 58.37% |
| **3 Automobiles & parts** | 14.63% | 16.96% | 45.49% |
| **4 Banks** | 0.68% | 0.72% | 50.01% |
| **5 Beverages** | 0.13% | 0.13% | 52.21% |
| **6 Chemicals** | 4.54% | 4.41% | 54.29% |
| **7 Construction & materials** | 0.32% | 0.61% | 27.67% |
| **8 Electricity** | 0.33% | 0.64% | 26.75% |
| **9 Electronic & electrical equipment** | 5.02% | 6.99% | 37.87% |
| **11 Financial services** | 0.01% | 0.12% | 5.32% |
| **12 Fixed line telecommunications** | 1.32% | 2.11% | 33.01% |
| **13 Food & drug retailers** | 0.23% | 0.18% | 67.55% |
| **14 Food producers** | 1.42% | 1.11% | 67.27% |
| **15 Forestry and paper** | 0.00% | 0.11% | 0.00% |
| **16 Gas, water & multiutilities** | 0.21% | 0.18% | 59.91% |
| **17 General industrials** | 2.14% | 2.18% | 51.74% |
| **18 General retailers** | 0.05% | 0.43% | 5.96% |
| **19 Health care equipment & services** | 1.11% | 1.76% | 33.21% |
| **20 Household goods** | 1.10% | 1.00% | 58.16% |
| **21 Industrial engineering** | 2.24% | 2.95% | 40.07% |
| **22 Industrial metals** | 0.41% | 0.66% | 32.62% |
| **23 Industrial transportation** | 0.05% | 0.07% | 36.08% |
| **24 Leisure goods** | 3.46% | 3.69% | 49.52% |
| **25 Life insurance** | 0.00% | 0.04% | 0.00% |
| **26 Media** | 0.18% | 0.47% | 20.44% |
| **27 Mining** | 0.10% | 0.21% | 24.28% |
| **28 Mobile telecommunications** | 0.21% | 0.19% | 58.41% |
| **30 Nonlife insurance** | 0.00% | 0.02% | 0.00% |
| **31 Oil & gas producers** | 1.33% | 1.54% | 45.60% |
| **32 Oil equipment, services & distribution** | 0.57% | 0.39% | 77.87% |
| **33 Personal goods** | 0.33% | 0.62% | 28.38% |
| **34 Pharmaceuticals & biotechnology** | 25.04% | 19.16% | 68.95% |
| **37 Software & computer services** | 8.54% | 7.14% | 63.05% |
| **38 Support services** | 0.30% | 0.35% | 44.53% |
| **39 Technology hardware & equipment** | 19.53% | 18.29% | 56.32% |
| **40 Tobacco** | 0.00% | 0.24% | 0.00% |
| **41 Travel & leisure** | 0.01% | 0.29% | 1.15% |

*Source:* DIUS and BERR, own elaboration

All figures are % of R&D investment by sector out of total population of firms; sectors with no firms were excluded: *2 Alternative energy, 10 Equity investment instruments, 29 Nonequity investment instruments, 35 Real estate investment & services, 36 Real estate investment trusts*

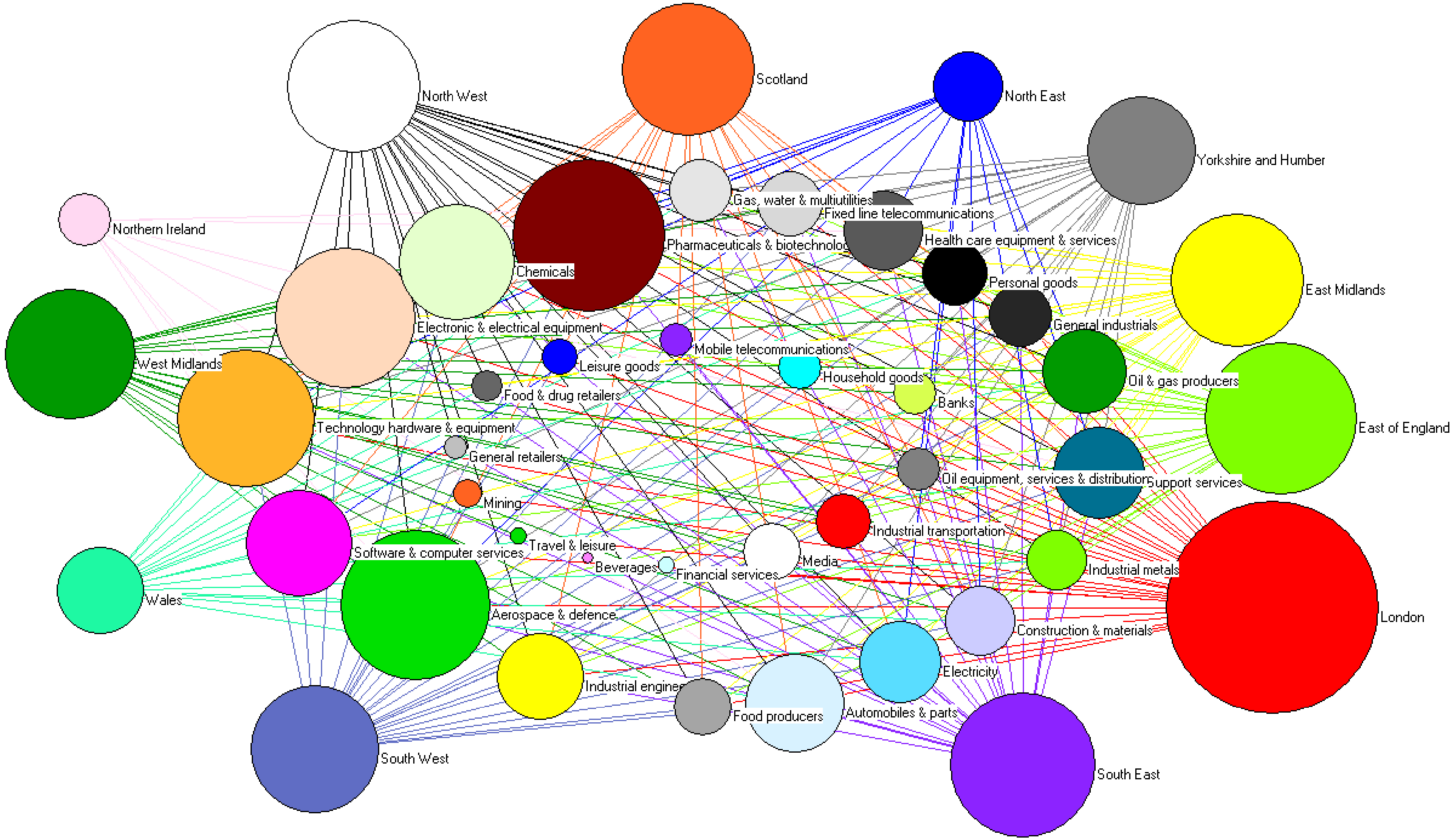
[1] Coronado et al (2008)

Figure 1: Proportion of R&D Investment by Sector *(£ of sector/£ of all sectors)*




*Source:* DIUS and BERR, own elaboration

Figure 2 University-Firm Interaction from a Regional and Sector Perspective




*Note*: The network pictured here is a shrunk network with the size of the vertices adjusted by the number of the interactions (vector) and colours (partition). The relation number (the number identifying the link between two vertices in the network) represents the number of a region for the easier identification of links.

Figure 3 Interactions between UK universities (green) and R&D-intensive firms (yellow)

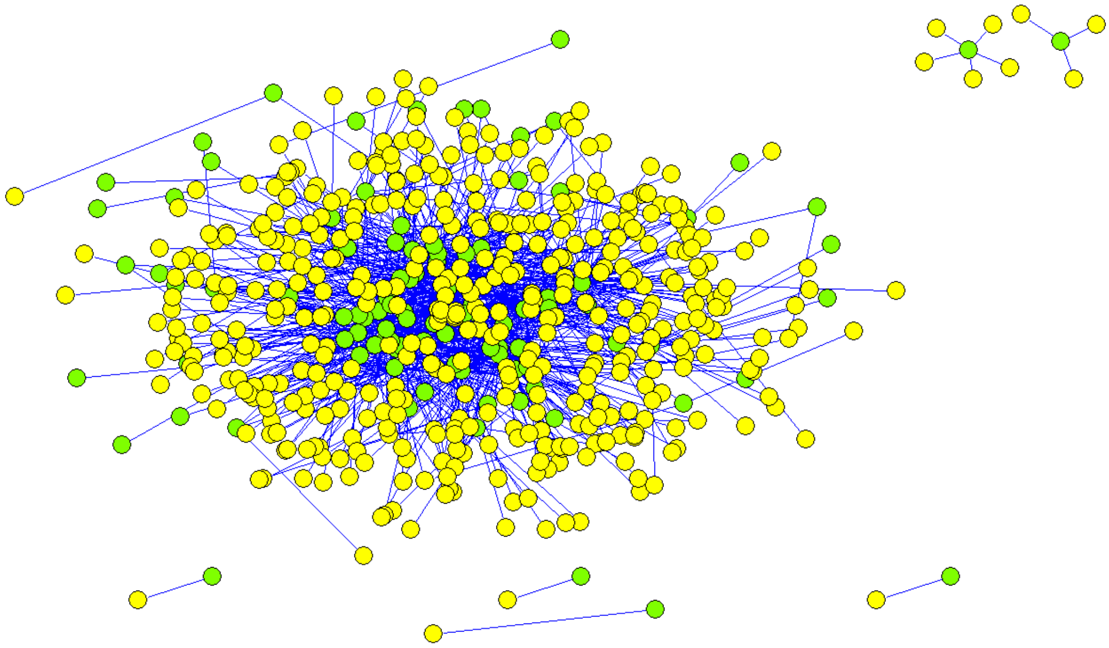


Table 3 Separate Components of the Network (universities interacting with respective firms)

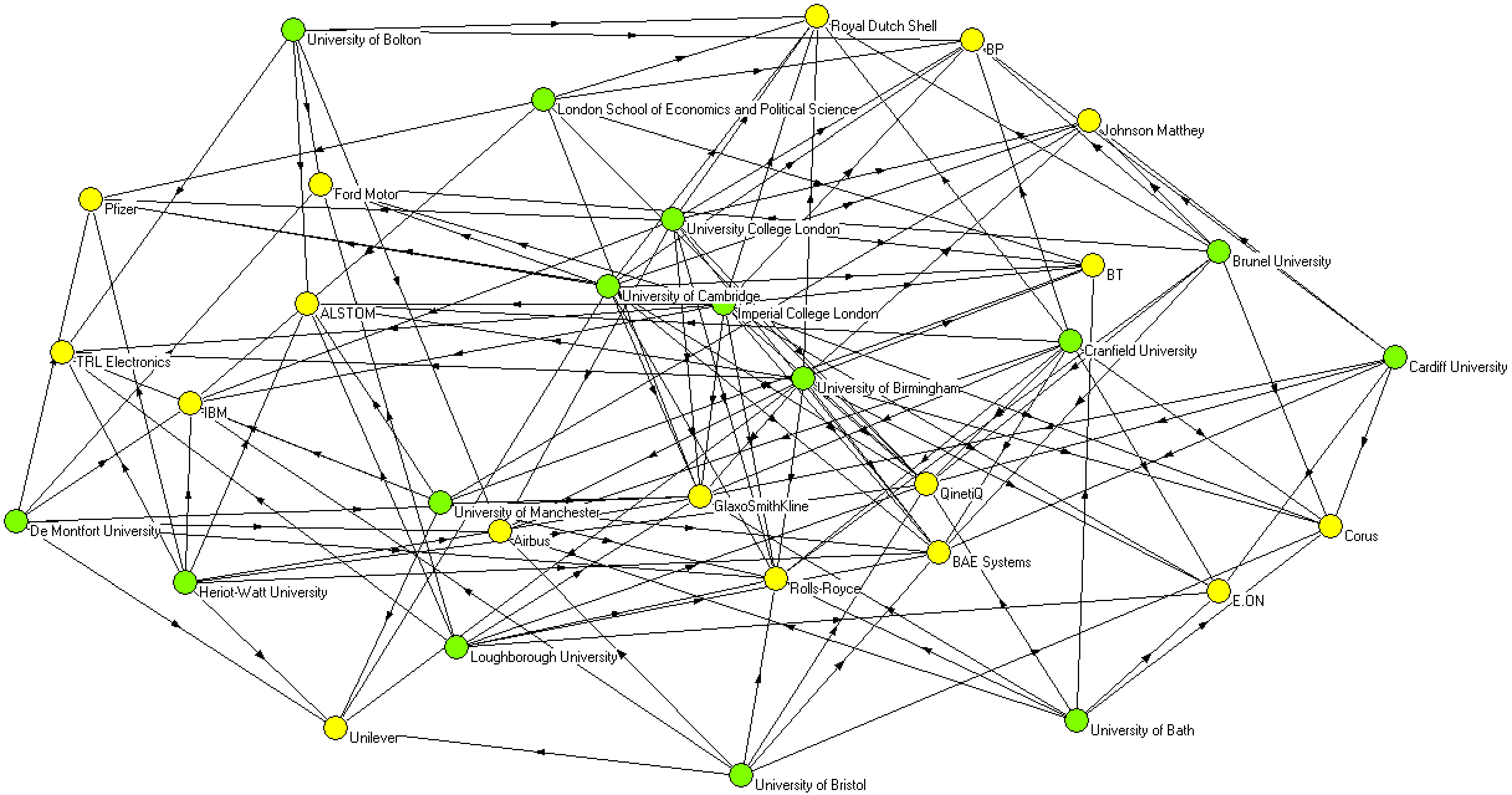
| **University** | **Firm** |
|---|---|
| University of Northumbria at Newcastle | International Power |
| University of Central Lancashire | INVISTA Textiles |
| University of the West of Scotland | Varian |
| Courtauld Institute of Art (*old*) | Tate & Lyle |
| University of Wolverhampton | FKI |
| | Expro |
| | Harmonic |
| | McKesson |
| | Wyeth |
| London Metropolitan University | Esso |
| | NACCO Industries |
| | Lucite International |

Table 4 Components of the Cohesive Subgroup

| Universities | Research Income £000s (2005/06) | R&D-Intensive Firms | R&D investment £m |
|---|---|---|---|
| Imperial College London | 204873 | Pfizer | 4064 |
| University of Cambridge | 203886 | Ford | 3768 |
| University College London | 184136 | GlaxoSmithKline | 3246 |
| University of Manchester | 146787 | IBM | 2887 |
| Cardiff University | 76787 | BT | 1252 |
| University of Birmingham | 76736 | Unilever | 638 |
| University of Bristol | 75888 | Royal Dutch Shell | 603 |
| Cranfield University | 41229 | Alstom | 412 |
| Loughborough University | 31531 | Airbus* | 397 |
| University of Bath | 25988 | Rolls-Royce | 454 |
| London School of Economics and Political Science | 15361 | BP | 284 |
| Heriot-Watt University | 15123 | BAE Systems | 176 |
| Brunel University | 11385 | Corus | 76 |
| De Montfort University (*new*) | 10564 | Johnson Matthey | 68 |
| University of Bolton (*new*) | 1595 | E.On | 51 |
| | | QinetiQ | 14 |
| | | TRL Electronics | 5 |

* *Note:* Airbus is a part of EADS, however, both the Research Council database and BERR & DIUS R&D Scoreboard list Airbus and EADS as separate entities.

Figure 4: The 6-core Cohesive Subgroup




*Notes*: The cohesive sub-network was energised with Kamada-Kawai's *free* algorithm

Table 5: Variables used in the regression analysis

| Variable | Description | Source |
|---|---|---|
| *Dependent* | | |
| University Research Income | Research income of UK universities including revenue gained from research grants and contracts (*continuous*) | HE-BCI |
| *Independent* | | |
| <u>University's internal resources</u> | | |
| University FTE employment | Full-time equivalent employment at UK universities (*continuous*) | HE-BCI |
| Portfolio of Active Patents | Number of active patents held by each university both domestic and overseas (*continuous*) | HE-BCI |
| University Type: 'Old' or 'New' | A distinction made between 'new' and 'old' universities. It takes value of 1 when a university is classified as 'old', and a value of 0 if classified as 'new' (*binary*) | |
| Percentage of Knowledge Transfers in Region | Percentage of knowledge transfer activities of each university that occurs within its own region (*continuous*) | HE-BCI |
| <u>University's networks</u> | | |
| University Total Number of Interactions with Firms | The identified number of interactions of universities with R&D-intensive firms. It shows more than one interaction with firm, as some might be with different branches of one firm or repeated interactions (*continuous*) | Interaction database R&D Scoreboard 2008 |
| University Interactions with Firms in its Region | The identified number of interactions of universities with firms that take place in the same region as the university. It takes account of multiple branches of firms that are located in the same region (*continuous*) | Interaction database R&D Scoreboard 2008 |
| University Interactions with Firms outside its Region | The identified number of interactions of universities with firms that take place outside a university's' own region. It takes account of multiple branches of firms that are located in various regions (*continuous*) | Interaction database R&D Scoreboard 2008 |
| <u>University's external environment</u> | | |
| University Location | Location is specified as 'core' and 'peripheral' according to classification of regions; 'core' regions are: London, South East, and East of England. A university based in 'core' regions takes value of 1; if based in 'peripheral' regions it takes value of 0 (*binary*) | HE-BCI |
| <u>Firms' innovation input</u> | | |
| Total R&D Expenditure of Firms Interacting with University | An aggregate amount of R&D investment of all firms interacting with each particular university. The expenditure figure is provided in £m (*continuous*) | R&D Scoreboard 2008 Interaction database |
| Total R&D Expenditure of Firms Interacting with University in the same Region | An aggregate amount of R&D investment of all firms interacting with each particular university, based in university's region. The expenditure figure is provided in £m (*continuous*) | R&D Scoreboard 2008 Interaction database |
| Total R&D Expenditure of Firms Interacting with University Located in a Different Region | An aggregate amount of R&D investment of all firms interacting with each particular university, based outside university's region. The expenditure figure is provided in £m (*continuous*) | R&D Scoreboard 2008 Interaction database |
| Total R&D of Interacting Firms in Region | An aggregate amount of R&D investment of firms interacting with and located in the same region as a particular university. The expenditure figure is provided in £m (*continuous*) | R&D Scoreboard 2008 Interaction database |

Table 6: Independent variable descriptive statistics

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| University FTE employment | 158 | 88.00 | 9442.00 | 1885.79 | 1773.21 |
| Portfolio of Active Patents | 157 | 0.00 | 504.00 | 46.83 | 95.33 |
| University type | 158 | 0.00 | 1.00 | 0.46 | 0.50 |
| Percentage of Knowledge Transfers in Region | 158 | 0.00 | 1.00 | 0.30 | 0.30 |
| University Total Number of Interactions with Firms | 158 | 0.00 | 93.00 | 8.51 | 15.34 |
| University Interactions in its Region | 158 | 0.00 | 29.00 | 2.37 | 4.35 |
| University Interactions outside its Region | 158 | 0.00 | 73.00 | 6.13 | 11.70 |
| University location | 158 | 0.00 | 1.00 | 0.41 | 0.49 |
| Total R&D Expenditure of Firms Interacting with University | 158 | 0.00 | 53280.20 | 4388.36 | 7734.44 |
| Total R&D Expenditure of Firms Interacting with University in the Same Region | 158 | 0.00 | 12615.53 | 857.40 | 2117.12 |
| Total R&D Expenditure of Firms Interacting with University Located in a Different Region | 158 | 0.00 | 45214.90 | 3530.96 | 6356.28 |
| Total R&D of Interacting Firms in Region | 158 | 3834.24 | 67664.21 | 31169.99 | 18887.64 |
| Valid N (listwise) | 157 | | | | |

Table 7 Correlation matrix

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | University Research Income | - | | | | | | | | | | | | |
| 2 | University FTE employment | .842** | - | | | | | | | | | | | |
| 3 | Portfolio of Active Patents | .775** | .682** | - | | | | | | | | | | |
| 4 | University type | .474** | .392** | .422** | - | | | | | | | | | |
| 5 | Percentage of Knowledge Transfers in Region | -.144 | -.060 | -.102 | -.263** | - | | | | | | | | |
| 6 | University Total Number of Interactions with Firms | .743** | .661** | .513** | .394** | -.153 | - | | | | | | | |
| 7 | University Interactions in its Region | .757** | .655** | .500** | .362** | -.111 | .878** | - | | | | | | |
| 8 | University Interactions outside its Region | .692** | .623** | .481** | .382** | *-.159** | .984** | .779** | - | | | | | |
| 9 | University location | .070 | -.072 | -.001 | .077 | -.027 | .032 | .118 | -.002 | - | | | | |
| 10 | Total R&D Expenditure of Firms Interacting with University | .684** | .583** | .456** | .334** | -.129 | .899** | .828** | .870** | .080 | - | | | |
| 11 | Total R&D Expenditure of Firms Interacting with University in the Same Region | .685** | .522** | .475** | .282** | -.027 | .626** | .809** | .520** | .268** | .730** | - | | |
| 12 | Total R&D Expenditure of Firms Interacting with University in a Different Region | .604** | .535** | .383** | .312** | -.147 | .885** | .738** | .886** | .008 | .974** | .555** | - | |
| 13 | Total R&D of Interacting Firms in Region | .053 | -.045 | -.012 | .038 | -.046 | .019 | .145 | -.029 | .903** | .073 | .284** | -.006 | - |

** Correlation significant at 0.01 level (2-tailed)
*  Correlation significant at 0.05 level (2-tailed)

Table 8 Impacts on University's research income generation estimated using robust Generalised Linear Model

| **Dependent Variable: University Research Income** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Model | 1 | | 2 | | 3 | | 4 | |
| University FTE employment | 1.03E+01 | (0.000) | 9.57E+00 | (0.000) | 9.53E+00 | (0.000) | 9.68E+00 | (0.000) |
| Portfolio of Active Patents | 1.17E+02 | (0.001) | 1.15E+02 | (0.000) | 9.95E+01 | (0.000) | 9.73E+01 | (0.000) |
| University type | 5.36E+03 | (0.031) | 5.74E+03 | (0.012) | 5.72E+03 | (0.010) | 5.33E+03 | (0.017) |
| Percentage of Knowledge Transfers in Region | -3.07E+03 | (0.391) | -3.65E+03 | (0.311) | -5.21E+03 | (0.145) | -5.84E+03 | (0.096) |
| University Total Number of Interactions with Firms | 4.40E+02 | (0.067) | | | | | | |
| University location | 5.71E+03 | (0.057) | 3.38E+03 | (0.202) | 8.17E+02 | (0.742) | 8.98E+03 | (0.076) |
| University Interactions in its Region | | | 2.30E+03 | (0.010) | 9.85E+02 | (0.215) | 1.14E+03 | (0.152) |
| University Interactions outside its Region | | | -1.25E+02 | (0.683) | 4.88E+02 | (0.076) | 4.28E+02 | (0.113) |
| Total R&D Expenditure of Firms Interacting with University in the Same Region | | | | | 3.46E+00 | (0.036) | 3.48E+00 | (0.036) |
| Total R&D Expenditure of Firms Interacting with University in a Different Region | | | | | -1.07E+00 | (0.041) | -1.07E+00 | (0.040) |
| Total R&D of Interacting Firms in Region | | | | | | | -2.39E-01 | (0.077) |
| Intercept | -1.36E+04 | (0.000) | -1.21E+04 | (0.000) | -9.67E+03 | (0.000) | -5.40E+03 | (0.160) |
| Observations | 157 | | 157 | | 157 | | 157 | |
| Log likelihood | -1.73E+10 | | -1.55E+10 | | -1.40E+10 | | -1.37E+10 | |
| Pearson Chi-Square | 3.45E+10 | | 3.10E+10 | | 2.80E+10 | | 2.75E+10 | |
| Regression (df) | 6 | | 7 | | 9 | | 10 | |
| Residual | 150 | | 149 | | 147 | | 146 | |
| Total | 156 | | 156 | | 156 | | 156 | |

Significance levels in brackets

*Note:* The variable: *Total R&D expenditure of firms collaborating with University* is excluded from the regression, as it came insignificant in all models. The two disaggregated variables (i.e. 'in' and 'outside') that include locational characteristics were used instead as they produce significant coefficients.