KNOWLEDGE SPILLOVERS AND SOURCES OF KNOWLEDGE IN THE MANUFACTURING SECTOR: LITERATURE REVIEW AND EMPIRICAL EVIDENCE FOR THE UK

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Abstract

This report provides a review of knowledge spillovers and sources of knowledge in the manufacturing sector. The literature reviewed indicates the importance of intangible investments in firms' internal knowledge assets. The weight of evidence also emphasises the importance of firms' absorptive capacity in increasing internal capabilities and in benefiting from external knowledge sources. We also highlight the importance of external knowledge and knowledge-assets (i.e., knowledge spillovers) in determining productivity and competitiveness, as well as the spatial dimension of knowledge flows in particular knowledge clusters. Our study subsequently provides an empirical analysis of firms' knowledge sourcing and cooperation behaviour for innovation activities in the UK manufacturing sector, using establishment-level data from recent four waves of the UK Innovation Survey covering the 2002-2010 period. Following the approach developed in Harris and Li (2009), we have constructed an empirical multi-index of absorptive capacity to measure a firm's ability to internalise and appropriate external knowledge for innovation activities. Our results show substantial heterogeneity across sectors; and overall, manufacturing (especially higher tech or advanced) makes the strongest use of knowledge sources and is associated with highest levels of absorptive capacity followed by Knowledge-Intensive Services (KIS), where the UK has a strong comparative advantage. There is evidence that manufacturers responded to external market conditions in their utilisation of knowledge sources and more specifically, firms were making greater use of knowledge sources in response to the recent economic recession.

Keywords: manufacturing; knowledge sourcing; innovation; absorptive capacity; inter-industry heterogeneity

JEL Codes: L25; O25; O32; R11

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Abbreviations

AC = Absorptive Capacity
ARD = Annual Respondents Database
GOR = Government Office Region
HEI = Higher Education Institutions
IDBR = Inter Departmental Business Register
KIS = Knowledge-intensive services
LKIS = Less knowledge-intensive services
MCA = Multiple correspondence analysis
ONS = Office for National Statistics
OECD = Organisation for Economic Co-operation and Development
SIC = Standard Industrial Classification
UKIS = UK Innovation Survey

Executive Summary

This report was commissioned by the Government Office for Science to conduct a review of knowledge spillovers and sources of knowledge in the manufacturing sector.

This first part of the report delivers a literature review on knowledge spillovers and sources of knowledge in the manufacturing sector, on the basis of the research specification.

Section 1 defines and discusses the key concepts that are used throughout the review. Section 2 focuses on the importance of internal knowledge and knowledge-assets in determining productivity and competitiveness. It covers recent developments in the theoretical and empirical literature.

The evidence reviewed indicates the importance of intangible investments in firms' internal knowledge assets. Besides investments into in-house R&D and the share of R&D personnel that have been traditionally considered as the main component of the internal knowledge assets, recent evidence highlights the importance of other types of intangible investments. UK firms spend more on non–R&D intangible assets than on R&D; 50% of UK firms spend on non-R&D intangible assets, whereas only 8 % spend on R&D (Awano et al. 2010).

The impact of in-house R&D investments on firm productivity is substantial; the rate of return on R&D is estimated to be around 14% - 40% for UK firms. Intangible assets account 10%-20% of the labour productivity growth at the firm level (Riley and Robinson 2011). Firms with patents have growth rates that are on average 10% higher than firms without patents (Hall et al. 2012). Holding a trademark or a design

right is associated with a performance premium of 16-17% (Greenhalgh and Rogers 2007; Bascavusoglu-Moreau and Tether 2011). At the national level, intangible capital accounts for 15-20% of labour productivity growth (Marrano, Haskel, and Wallis 2009).

Another concept that is very closely linked to intangible assets is the notion of absorptive capacity. Throughout the report, the weight of evidence emphasises the importance of firms' absorptive capacity in increasing internal capabilities and in benefiting from external knowledge sources. The reviewed evidence suggests that more direct measures of absorptive capacity as constructed by Harris and Li (2009) are clearly needed.

Section 3 focuses on the importance of external knowledge and knowledge-assets (i.e., knowledge spillovers) in determining productivity and competitiveness. We first review the literature on engaging in formal collaborative agreements and using external knowledge sources. Evidence suggests that UK firms are increasingly engaging in formal collaboration with different types of partners. The reviewed studies indicate that vertical linkages, through customers and suppliers are considered as the main sources of knowledge for innovation in UK firms. Firms that are more open to external collaboration are more likely to innovate and innovate better. Vertical linkages and cooperation within the business group is found to account for 50% of the total factor productivity growth (Crespi et al. 2008) and cooperation with higher education institutes, for 16.3% (Harris, Li, and Moffat 2012)

Firms can also benefit from knowledge developed by other firms and/or institutions without engaging in collaborative agreements or economic transactions. These are spillover effects, because the user who benefits does not pay the full economic cost of producing them. The review of the literature suggests that spillovers may vary in importance and occur through different routines. Trade appears to be an important channel of spillovers. There is some evidence on R&D spillovers via imports, and exporting is found to be associated with learning effects and higher productivity. Regarding FDI-spillovers, although foreign-owned firms are found to be more productive than their domestic counterparts, the empirical evidence reviewed is mixed. The positive impact of FDI-spillovers is closely linked to the domestic firms' absorptive capacity and the type of FDI.

Section 4 focuses on the spatial dimension of knowledge flows and the identification of the specific mechanisms by which spillovers are transmitted and their variation across locations. The literature surveyed indicates a positive effect of being located in a cluster, however; studies reviewed present a mixed picture of local knowledge spillovers. There is some evidence on the importance of labour market dynamics and social interaction at the level of the individual in firms' and clusters' knowledge creation processes. However, the positive impact of knowledge spillovers seems to be closely dependent on sectoral and institutional characteristics. The main mechanism of knowledge diffusion is through labour mobility. This finding highlights the importance of the tacit knowledge embedded in people. In this sense, clusters act as a hub for the attraction of global talents. High-technology clusters are found to be more likely to generate knowledge spillovers. However, the nature of the technology is closely related to the issues of intellectual property. Excessive non-disclosure agreements act as a barrier to knowledge diffusion. The regional science-base and university-industry interactions also arise as an important factor. Geographic proximity appears to facilitate personal interactions, however knowledge flows are not confined to geographical spaces; successful firms access knowledge regardless of its geographical location, through digital communication technologies. However, local and global networks should not be seen as conflicting, they both have important but different and sometimes complementary roles to play (Christopherson, Kitson, and Michie 2008). Successful clusters enable local firms to be embedded simultaneously in knowledge exchanges at different geographic scales.

The second part of the report presents an empirical analysis of firms' knowledge sourcing and cooperation behaviour for innovation activities in the UK manufacturing sector, using establishment-level data from recent four waves of the UK Innovation Survey (henceforth UKIS), covering the 2002-2010 period. In terms of inter-sectoral differences, manufacturing firms represent the largest users of knowledge from most sources. Suppliers and clients represent main sources of knowledge to around half of manufacturers. Higher tech manufacturers leverage knowledge across a wider spectrum of sources at a higher rate than lower tech ones. Also there is an especially notable difference in the percentage of high tech respondents (vis-à-vis low or medium-low tech firms) stating that they utilise knowledge transfer from HEIs, scientific journals and conferences.

In terms of the evolution of firms' knowledge sourcing behaviour over time there was a general downward trend in the utilisation of knowledge within most categories across the economy. The decline seemed most substantial during the 2006-2008 period of economic recession before an incremental upswing was seen in the most recent 2008-2010 period.
Suppliers, clients and competitors are very important sources for respondents across all UK regions. Furthermore, evidence suggests that there is a very strong correlation between the size of a manufacturing firm and its orientation of knowledge linkage with external sources. In contrast, the relationship between firm age and knowledge sourcing may not be a distinctive one.
Foreign subsidiaries in UK manufacturing routinely outperform their indigenous counterparts in leveraging external knowledge across all sources. Exporters are also found to be often twice as likely to make use of various knowledge sources in innovation; and even exporters in the low tech industries systematically utilise various knowledge sources at a higher rate compared with their non-exporting high tech counterparts.

Within manufacturing suppliers and clients are by far the most important means of international cooperation across all sectors and many sectors appear to have especially low values for cooperation with HEIs and government at the global level. Advanced manufacturers are around twice as likely to cooperate internationally with all partners relative to average manufactures.

Following the approach developed in Harris and Li (2009), we have constructed an empirical multi-index of absorptive capacity to measure a firm's ability to internalise and appropriate external knowledge for innovation activities. Overall manufacturing firms appear to have the highest absorptive capacity for general external knowledge (the principal type of absorptive capacity) and also a noticeable advantage in its absorptive capacity for national and international cooperation, and business strategy and practice. Another sector that stands out is the Knowledge-Intensive Services (KIS) which dominates in its absorptive capacity for business strategy and practice, national and international cooperation and is second only to manufacturing in its principal capacity for general external knowledge.

A number of 'heat maps' showing performance of absorptive capacity for UK manufacturers within local authorities provide powerful insights into the geographical variation. In terms of the absorptive capacity for general external knowledge, it is suggested that the areas with strong manufacturing component tend to have higher capacity. The areas with higher level of capacity in the manufacturing sector are seen around the UK periphery (Scotland, Wales and parts of Northern England) as well as strong areas embedded within the Midlands, South East and South West.

Our findings here echo those highlighted by Harris and Moffat (2012c), who found that knowledge spillovers in the UK were distributed across the country and not just confined to the Capital or other major cities. As to the capacity for cooperation at the international level, the strongest areas are similar to those found at the national level - there are clusters of relative strength in Wales and Scotland, the North East and a band in the Midlands. Given the 'hub' effect of London and the South East, these regions perform more strongly on their absorptive capacity for business strategies and practices. Lastly, in terms of the regional absorptive capacity for specialist knowledge from HEIs and government, Scotland is associated with higher scores as are the North East and North West and the South of Wales.

Lastly, we also investigate the nexus between knowledge sources, cooperation partners used in innovation activities, formal R&D strategies, innovation output, and finally IP protection strategies. Our results suggest that product innovators are also likely to be process innovators (and vice versa), and that the more radical innovators (with 'blue sky' innovations) turn to combine 'make' (intramural R&D) and 'cooperation' in their R&D investment strategy. Further results suggest a clear and close association between 'blue sky' innovation and exploiting value from such path-breaking innovation by registering patents and industrial designs. In terms of firms' cooperation behaviour in innovation, the firms engaged in cooperation with one national partner tend to also collaborate with other types of partners at national level;

and those that participate in cooperation with overseas partners in one form are also more likely to engage in international cooperation in another form.

Overall, our results suggest that manufacturing (especially higher tech or advanced) makes the strongest use of knowledge sources and is associated with highest levels of absorptive capacity followed by Knowledge-Intensive Services (KIS), where the UK has a strong comparative advantage. There is evidence that manufacturers responded to external market conditions in their utilisation of knowledge sources and more specifically, firms were making greater use of knowledge sources in response to the recent economic recession. However, the challenge for all sectors of the economy will be to continue to make the best use of all sources of knowledge as economic conditions in the UK and abroad improve.

1. Concepts and Definitions

The ability to create, store and use knowledge allows firms to exploit the unique properties of knowledge to gain competitive advantage. Knowledge has similar properties to public goods, in the sense that it is non-rival and non-excludable. The non-rival nature of knowledge implies that it is not depleted by use. Its non-excludable nature means that once knowledge is created, it is impossible -or very costly- to prevent others to benefit from it. A useful feature to bear in mind regarding the nature of knowledge is the distinction between codified and tacit knowledge. Codified or rule based knowledge can be written down and stored, whereas tacit knowledge is acquired by experience and resides with the individual as know-how and experience.

One approach to assess the impact of knowledge on competitive performance begins with the work of Griliches (1979; 1986). He analyses a knowledge production function which defines the relationship between the inputs into the production of knowledge and its output that is economically useful new technological knowledge (Acs, Anselin, and Varga 2002). The rate of production of economically new knowledge (innovation) depends on the existing stock of "knowledge" assets, including the labour force committed to research and development (R&D) activities. Knowledge assets can be broadly defined as a combination of tangible and intangible assets. Tangibles are the assets that are physical in nature, such as land, machinery, equipment and capital. Intangibles are the assets that are not physical in nature, defined as "*non-material factors that contribute to enterprise performance in the production of goods or the provision of services, or that are expected to generate future economic benefits to the entities or individuals that control their deployment*" (Eustace 2000, 31). In their seminal work on the measurement of intangibles, Corrado et al. (2005) categorize investments in intangible capital into three broad categories; computerised information, innovative property and economic competencies. Here we follow a simpler categorisation, and distinguish between formal and informal intangible assets, depending on the nature of knowledge involved. Formal intangible assets relate to codified knowledge and are often proxied by R&D expenditures or intellectual property data, such as brands, patents or trade-marks. Informal intangible assets refer to tacit knowledge, and they are, therefore, more difficult to measure (Howells 1996).

Besides internal assets, firms also need external inputs to innovate. There are various ways for the firms to access external knowledge. They can obtain external inputs for knowledge via market transactions; they can buy external knowledge assets from other firms and organisations by paying the full price or they can collaborate by means of formal agreements. Or they can benefit from external knowledge without getting involved in any form of formal transactions via externalities.

Externalities arise when the activities of one agent induce (positive or negative) external effects on other agents in the market that are not fully reflected or “internalized” in market prices (Conlon et al. 2012). This idea of capturing benefits from other parties’ investment in knowledge without paying its full price is called “spillovers” by the economists; knowledge can “spill over” from one firm/institution to another. For example, competing firms that imitate a successful innovation, and firms whose own research benefits from observation of the successes and failures of others' research efforts all gain such spillover benefits (Jaffe 1998).

The concept of spillovers is very closely related to the public good nature of knowledge. As knowledge is non-rival, spillovers imply that the benefit of the new knowledge to society as a whole outweighs the loss of potential economic gains the knowledge-creator could have made from keeping it. However, the creator’s ex-post inability to capture the full benefits of new knowledge will diminish the incentive to invest in developing knowledge in the first place. At the limit, the benefits of an activity may be so diffuse that no individual or firm would undertake the activity on their own.

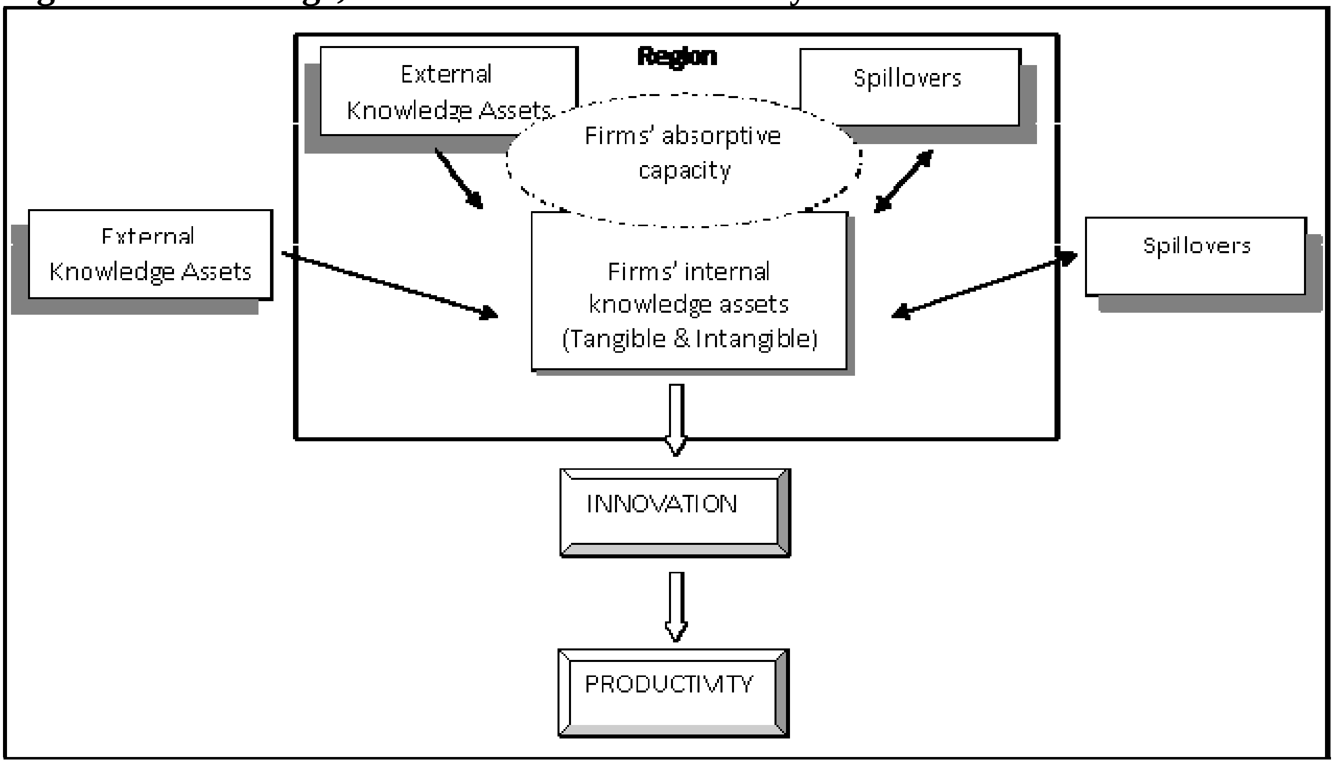
Spillovers can arise in multiple ways. They can be intentional on the part of the innovator such as the publication of scientific papers, or can be disclosed in a patent as a quid pro quo for the granting of monopoly rights, or they can occur despite any desire of the inventor via the sales of the new product (Jaffe 1998).

However, in order to recognise, access, adopt and benefit from these external sources of knowledge, via either market internalised transactions or by externalities, firms need to have a certain level of absorptive capacity. Absorptive capacity is defined as capability to identify, assimilate, and exploit external new information. It is this combination of internal tangible and intangible assets with external sources of knowledge through the absorptive capacity of the firm that yields innovations which, in turn, will increase firms' (and regions, sectors, countries) productivity.

Analyses of firms’ access to external knowledge have frequently emphasized the importance of spatial proximity, particularly knowledge spilling from one firm and/or institution to another. Despite its public good properties, knowledge does not flow instantaneously from one firm/organisation to another. The transfer of tacit knowledge especially requires direct, face-to-face interaction, and hence, geographical proximity (Audretsch and Feldman 1996). These positive externalities arising from geographical proximity are generally called agglomeration economies. In the context of innovation activities, it leads to local knowledge spillovers defined as “knowledge externalities bounded in space”, which allow firms close to key knowledge sources to be more innovative than firms located elsewhere (Breschi and Lissoni 2001b). Specific modes of local interactions between firms, universities, venture capitalists may generate specific informal institutions, and enhance information flows among agents located within the same geographical agglomeration (Doring and Schnellenbach 2006). Because the ability to absorb and adopt new knowledge depends on the institutional framework which may vary across regions, these differences may help to account for growth rate differences.

A schematic framework describing the relationships between knowledge, innovation and productivity is schematised in Figure 1. We will discuss internal knowledge assets, as well as absorptive capacity in the following section. The third section will focus on external knowledge assets and spillovers. The final section will explore the geographic proximity, particularly the mechanisms through which the knowledge flows.

Figure 1: Knowledge, Innovation and Productivity Framework



2. Internal Knowledge Assets

Tangible assets, such as capital and labour, are no longer the generating factors of competitive advantage as they are easily available. Intangible assets have been receiving increasing attention as a key input in firms' performance (Goodridge, Haskel, and Wallis 2012; Awano et al. 2010; Borgo et al. 2012; Corrado, Hulten, and Sichel 2009; Harris and Moffat 2012a).

Within the formal intangible assets, investment in in-house R&D and the share of R&D personnel have been considered as the main input to explain firms (sectors, countries)' innovative performance (Griliches 1986; Griliches 1979). However, R&D spending is highly skewed; only a very small number of firms report investing in in-house R&D. Bloom and van Reenen (2002) show that 12 largest UK firms account for 80% of R&D expenditures between 1968 and 1996. Similarly, Criscuolo and Haskel (2003) report that the median firm in the two UK waves of Community Innovation Survey (UKIS) 1994-1996 and 1998-2000 spends nothing on R&D. These numbers are confirmed at the aggregate level by a recent survey on the conduct of R&D in the UK by business, government and higher education sectors (Hughes and Mina 2012). Hughes and Mina (2012) report that the largest 10 business R&D spenders account for 34% of all UK R&D in 2009, and the largest 50 spenders for 56%. They also show that business and government expenditures on R&D (as a percent of GDP) have been decreasing whereas the share of higher education is increasing since 1990s.

Other formal intangible assets include factors over which legal rights have been assigned, such as patents, marks and copyrights. UK firms' patenting behaviour also follows the trends in R&D spending. Bloom and van Reenen (2002) show that most of their sample (firms who had at least one patent during 1968-1996) involved in very small amount of patenting activity, with half the sample receiving more than 25 patents. This finding has been confirmed for a more recent period of analysis (1996-2008); only 1.7 % of all registered firms in the UK patent (Hall et al. 2012). The distribution of trademarks seem more homogenous; in a sample of 1600 large UK firms Greenhalgh and Rogers (2007) report that the average propensity to apply for a UK trademark is around 42% in manufacturing.

Overall, intangible investment is reported to have risen sharply in the UK, especially in the areas of computerised information, design, training and business process re-organisation (Marrano, Haskel, and Wallis 2009). A recent survey aiming to measure the investments of UK firms in intangible assets find that the incidence of non–R&D intangible spending is much more widespread than R&D spending; 50% of UK firms spend on non-R&D intangible assets, whereas only 8 % spend on R&D (Awano et al. 2010). The overall level of intangible spending is considerable, around £39bn in this survey, distributed between software (£11bn), branding (£10bn), R&D (£10bn), training (£7bn) and design and business process improvement (£1bn each) (Awano et al. 2010).

Table 1: Intangible Investment in the UK per category as a share of total intangible investments

	1990		1995		2000		2008	
	£bn	**%**	**£bn**	**%**	**£bn**	**%**	**£bn**	**%**
Software development	£6bn	11%	£10bn	14%	£16bn	17%	£22bn	16%
R&D	£8bn	14%	£9bn	13%	£12bn	13%	£16bn	12%
Design	£13bn	23%	£13bn	19%	£15bn	16%	£23bn	17%
Mineral exploitation/Copyrights	£3bn	5%	£3bn	4%	£2bn	2%	£4bn	3%
Branding	£5bn	9%	£7bn	10%	£12bn	13%	£15bn	11%
Training	£12bn	21%	£15bn	22%	£21bn	22%	£27bn	20%
Organisational Capital	£9bn	16%	£12bn	17%	£17bn	18%	£31bn	22%
All intangibles	£56bn		£69bn		£95bn		£138bn	
All tangibles	£67bn		£62bn		£87bn		£104bn	

Source: London Economics' adaptation from Haskel et al. (2011) (Conlon et al. 2012)

These findings confirm that firms can gain access to knowledge elsewhere, and that formal intangible assets are not the only source of knowledge creation. Other types of investments not counted as R&D are also important such as organisational, network or human capital. For example, Corrado et al. (2005) categorize investments in intangible capital into three broad categories; computerised information, innovative property and economic competencies. Computerised information includes knowledge embedded in computer software programs and computerised databases. Innovative property corresponds to knowledge acquired through scientific R&D and non-scientific inventive and creative activities. Economic competencies relate to the value of firm-specific human and structural resources. Having assessed the extent of intangible assets, we will now review the studies evaluating the impact of different intangible assets.

In one of the first studies evaluating the impact of R&D on UK productivity, Wakelin (2001) estimates that every additional pound spend on R&D will increase the output by £1.27, for the 1988-1992 period. However, the rate of return on R&D (estimated around 29%) varies considerably following firms' innovation history and sectoral characteristics. Innovative firms spent more on R&D expenditure relative to sales than non-innovating firms (2.3% against 0.8%) and have a higher rate of return than the R&D expenditure of non-innovating firms, particularly in sectors which are net users of innovations (Wakelin 2001, 1089). Griffith et al. (2006) calculate a rate of return for the R&D of 14% for the mean firm in the sample, Bond et al. (2003)

estimate the R&D rate of return to 38%, and Rogers (2009) find that it ranges between 40% to 58% in the manufacturing sector (See also Table A1 in the Annex). Positive effect of in-house R&D expenditure on firm productivity via higher innovative sales have been confirmed by other studies based on the UK wave of the Community Innovation Survey (Frenz and Ietto-Gillies 2009).

Galindo-Rueda and Haskel (2005) combine the data from Annual Business Inquiry (ABI) and National Employer Skills Survey for England, and explore the effects of workplace skills on firm productivity. They show that one percentage point increase in high skilled employees leads to 0.30% increase in firm-level productivity in manufacturing. Riley and Robinson (2011) combine individual occupation and wage data from the Annual Survey of Hours and Earnings (ASHE) and the labour Force Survey with data from Business Structure Database (BSD) and Annual Business Inquiry (ABI). Following Corrado et al. (2005)'s categorisation of intangible investments, authors use employees' occupations and earnings to estimate the impact of intangibles on labour productivity growth during 1998-2006. They find that organisational capital and investments in R&D contributed an equal share of 0.13% - 0.17% to productivity growth, while the contribution of the ICT capital was estimated between 0.08% - 0.13%.

Regarding the impact of patent activities, both Bloom and van Reenen (2002) and Hall et al. (2012) point to positive effects of patenting on firm performance. Equally, using trademarks as a form of formal intangible assets, Greenhalgh and Rogers (2007) show that stock market values are positively associated with firms' trade mark activities, and that manufacturing firms with a trademark both at UK and European level has a performance premium of 16%. Similarly, holding a design registered in the UK in the late 1990s and early 2000s is found to be associated on average with a performance premium of 17%, although this positive effect has disappeared for the most recent years (Bascavusoglu-Moreau and Tether 2011).

At a cross-country level, recent evidence shows a correlation between total factor productivity growth and intangible investments (Ark et al. 2009; Corrado, Haskel, and Jona-Lasinio 2011). At the macro level, intangible investments are reported to be as important as tangible investments, or even more important in case of US and UK. Corrado et al. (2005) capitalise intangibles and expand the traditional growth model to include intangible input and output. Authors' findings show that the exclusion of intangibles assets in national accounts entails underestimation of labour productivity growth by 10-20 % in the US (Corrado, Hulten, and Sichel 2009). With the same methodology, Marrano, Haskel and Wallis (2009) find that 15% of labour productivity growth is accounted for intangible capital deepening in 1979-2005 and 20% in 1995-2003.

Another concept that is very closely linked to intangible assets and tacit knowledge is the notion absorptive capacity (For an extensive review of intangible assets and absorptive capacity, see Harris & Moffat (2012)). Cohen & Levinthal (1990, 569–

570) first coined the term ‘absorptive capacity’, defining it as: ‘the firm’s ability to identify, assimilate and exploit knowledge from the environment’. Subsequently they adopted a slightly wider view as: ‘… an ability to recognize the value of new information, assimilate it, and apply it to commercial ends’ (Cohen 1989, 128). Putting the two together provides a ‘classical’ view of absorptive capacity: the identification and recognition of new information, both internal and external, and its assimilation, application and exploitation for commercial ends.

The concept of absorptive capacity emphasises on the fact that the external knowledge is not automatically and effortlessly absorbed by the firm, and therefore, is not equally absorbed by all firms (Fabrizio 2009). Existing literature has considered various activities that can contribute and proxy firms’ absorptive capacity, such as investments in R&D (Wesley Cohen and Levin 1989), firms’ basic research (Rosenberg 1990; Dyer and Singh 1998), routines (Zahra and George 2002), technological overlap (Mowery, Oxley, and Silverman 1996) and collaborations with universities (Cockburn and Henderson 1998).
Although the theoretical definitions and discussions on the notion of absorptive capacity are numerous, the empirical estimation of the concept itself is very scarce. Most of the empirical studies proxy absorptive capacity with the in-house R&D investments or the share of the R&D personnel. These proxies fail to capture the realisation and accumulation of the absorptive capacity (Harris and Moffat 2012a). The most comprehensive set of empirical measure of absorptive capacity for the UK to our knowledge is estimated by Harris and Li (2009). Based on the 3 waves of the UK Innovation survey, the authors use factor analysis to group firms regarding the following capabilities: exploitation of external sources of knowledge, networking with external bodies at the national level, implementation of new organisational structures and acquisition/absorption of codified scientific knowledge. Firms that use greater external knowledge, cooperate with national partners, and that have a higher quality of corporate strategy and management techniques are found to be more likely to undertake R&D and to innovate (Harris and Moffat 2012b). Among the different aspects of absorptive capacity, acquiring external knowledge seems to be the most important, with a standard deviation increase in this variable increasing the likelihood of innovating by 17%, followed by national cooperation (6%) and corporate strategy and management techniques (5%) (Harris and Moffat 2012b).

Overall, this brief survey of firms’ internal knowledge assets suggests that there is still need to develop concept and measures to assess the various dimensions of intangible assets. Existing empirical research shows that intangible assets account for 0.1-0.2% of the labour productivity growth at the firm level (Riley and Robinson 2011). Firms with patents have growth rates that are on average 10 per cent (in level) above those without patents, although this correlation is not statistically significant (Hall et al. 2012), however; holding a trademark or a design right is associated with a performance premium of 16-17% (Greenhalgh and Rogers 2007; Bascavusoglu-Moreau and Tether 2011). At the national level, intangible capital accounted for 15-20% of labour productivity growth (Marrano, Haskel, and Wallis 2009). Different aspects of absorptive capacity are found to increase the likelihood of innovation at the firm level and innovation raised growth in output per person-hour in the UK by almost 2% p.a. in the 2000s, which is 73% of labour productivity growth (Haskel et al. 2009).

Although firms can develop and acquire knowledge internally, few possess all the inputs needed for successful and sustainable technological development, therefore firms need to use external sources to acquire and internalize knowledge (Almeida, Dokko, and Rosenkopf 2003; Harris 2011). The recent empirical studies also point to the importance of external knowledge sources and how internal and external knowledge is intertwined and crucial for firm performance. In the following section, we will overview the literature on these external sources of knowledge.

Summary of the findings:

- Intangible assets have been receiving increasing attention as the key input in firms' performance.
- Within the formal intangible assets, the distributions of R&D spending, patents and trademarks are found to be highly skewed both at firm and the aggregate level.
- Non-R&D intangible spending is more widespread than R&D spending, highlighting the importance of informal intangible assets such as organisational, network or human capital.
- The contribution of ICT capital on UK productivity growth is estimated to range between 0.08%-0.13%, and organisational capital and R&D have an equal share of 0.13%-0.17%.
- Holding a design right or a trademark has a performance premium of 16-17%. Although patenting firms seem to perform better than non-patenting firms, this positive effect is not statistically significant.
- At the aggregate level, 20% (15%) of the UK's labour productivity growth between 1995-2003 (1979-2005) is accounted for by the intangible capital deepening.
- At the cross-country level, evidence shows a correlation between total factor productivity growth and intangible investments.
- Absorptive capacity, i.e. firm's ability to identify, assimilate and exploit knowledge from the environment is identified as a crucial factor.
- Among the different aspects of absorptive capacity (other than in-house R&D and share of R&D personnel), acquiring external knowledge seems to be the most important factor to increase the likelihood of innovation.

3. External Knowledge Assets and Knowledge Spillovers

3.1 Formal Collaborations and Cooperations

In order to remain competitive, it is no longer enough to rely on internal knowledge assets, but being open to external sources, particularly for cooperation with different partners as well as for knowledge transfer from universities. There is extensive research evidence on sources of knowledge for business innovation and on the determinants and impacts of the collaboration on firm performance. In this section we shall firstly review evidence on sources of knowledge, then the characteristics of UK firms' cooperative behaviour, and finally the impact of engaging in collaborative agreements on firm performance.

Firms use multiple sources of knowledge for innovation, of which, by far the most frequently cited are customers, suppliers and competitors, alongside their own internal knowledge base. Universities are amongst the least frequently cited sources (Laursen and Salter 2006; Cosh, Hughes, and Lester 2006).

Turning now to the patterns of cooperation, Tether (2002) provides an analysis of R&D cooperation in relation with different types of innovation activities in the UK. R&D cooperation is shown to be more common among firms that introduce radical innovations, i.e. innovations that are new to the market. Engaging in in-house R&D activities as well as its intensity tends to increase the propensity to cooperate. More specifically, engaging in continuous R&D activities shows a significant impact on the probability to cooperate with customers, competitors and consultants, while the intensity of R&D activities increases R&D cooperations with suppliers and universities. Laursen and Salter (2004) corroborate the latter; UK firms which engage in R&D and use other external sources of knowledge also tend to use university research more intensively. On the other hand, in a comparison of the UK and US industry-university ecosystem, Cosh and Hughes (2009) report that more UK firms report direct use of the science base, compared to the US, however they attach less value to it.

In a cross-country (UK, France, Germany, Spain) study on the determinants of cooperation, Abramovsky et al. (2009) shows that the perceived importance of knowledge sources (also called incoming spillovers, see Cassiman and Veugelers (2009)) and appropriability explains co-operative R&D in the UK. Regarding to the objectives of engaging in cooperative agreements, Love and Roper (2004) report that increased speed to market as a key reason for UK plants for inter-plant collaboration. In a comparison with German plants, UK plants are found to be more likely to collaborate with other group companies than were their German counterparts (Love and Roper 2004).

Regarding to the effects of collaborations, engaging in cooperative agreements seems to have ambiguous impact on innovative performance, measured by the share of sales due to innovative products. Some empirical studies have found a positive impact (such as Criscuolo and Haskel (2003) on the UK, Klomp and van Leeuwen (2001) and Belderbos et al. (2004) on the Netherlands, Loof and Heshmati (2002) on Sweden, among others) whereas others failed to find significant effect of cooperation on innovative performance (Janz, Lööf, & Peters, 2003 on Germany and Sweden). However, most of the studies have included a cooperation variable in empirical models explaining differences in firms' innovation outputs (Janz, Lööf, and Peters 2003; Klomp and Van Leeuwen 2001; Lööf and Heshmati 2002; Criscuolo and Haskel 2003) without systematically evaluating the differences among cooperation partners. These include competitors, users and suppliers, universities and research institutes, among others.

Cooperation with competitors is often motivated by concerns regarding knowledge appropriability, knowledge exchange or cost sharing (Miotti and Sachwald 2003; Gallié and Roux 2010). Belberdos et al. (2004) find a positive impact of cooperation with competitors both on labour productivity and on innovative sales productivity in Dutch firms, however for Germany Janz et al.(2003) show a negative effect and Miotti and Sachwald (2003) fail to find any significant impact.

Collaborating with customers is an important way for a firm to improve its innovative capabilities and performance (Tether 2002; Belderbos, Carree, and Lokshin 2004). By learning about lead customers' needs and expectations, firms are better able to identify market opportunities, new trends and solutions by learning about their customers' needs and expectations (Hippel 1976). In the UK, firms are increasingly choosing to engage in collaborative agreements with their customers, over the other types of partners. Users, as both firms and individual customers, may also be actively involved in the innovation process, by creating and/or modifying products and services according to their own needs. It is estimated that UK consumers, as a group, spend more on consumer product development than commercial enterprises (Hippel, Ogawa, and Jong 2011). However, once again, the empirical studies show mixed results regarding the impact of cooperation with customers. In a cross-country study across four European countries, Freitas, Clausen, Fontana and Verspagen (2010) find a positive benefit to engaging with customers. Freel (2005) corroborates this positive impact on product innovation performance in small and medium sized firms in the northern Britain. However, Nieto and Santamaría (2007) find that the benefits of collaborating with customers only prevail for incremental innovations in Spain. Belderbos, et al. (2004) show that collaboration with clients has no impact on innovative sales, whereas Lööf and Heshmati (2002) find a negative relationship between customer collaboration and product innovation performance.

Universities and government research institutes are important contributors to the supply of new scientific and technological knowledge (Lundvall 1992). Belderbos et al. (2004) and Lööf and Heshmati (2002) report a positive impact of university cooperation on innovative sales.

For the UK, most of the studies are based on different waves of UKIS. Frenz and Ietto-Gillies (2009) do not find any impact of engaging in collaborative agreements on the either the likelihood of innovation nor the innovative sales. Iammarino et al. (2012) explore the impact of different types of cooperation on firm innovativeness, taking into account firms' regional location. Vertical cooperation with customers and suppliers, horizontal cooperation with universities and horizontal cooperation within the business group are found to increase firms' technological capabilities (Iammarino et al. 2012). However, authors highlight considerable differences between the regions.

Two studies combine UKIS with Annual Respondent Databases (ARD) to estimate the impact of collaboration on firm productivity. Harris et al. (2012) estimate that collaborating with higher education institutions increases the total factor productivity by around 16.3%. Crespi et al. (2008) show that the main sources of knowledge are competitors, suppliers and other plants that belong to the same business group, and that they account 50% of total factor productivity growth. They find that universities act as an important source of information for patenting activities (Crespi et al. 2008), but find no effect on productivity.

Based on a bespoke survey, De Propris (2002) shows that vertical collaborations are particularly important for innovation, compared to horizontal linkages, moreover the author empirically demonstrates that higher levels of vertical cooperations between firms over a range of activities induce higher levels of innovation.

Based on the UKIS, and using firms' access to external sources of knowledge, Laursen and Salter (2006) explore how differences in search strategies among firms influence their ability to achieve different levels of novelty in their innovative activities. Although both using external sources of knowledge and the intensity of use are found to increase firms' innovativeness, the benefits associated with openness are subject to decreasing returns.

Recently, it has been argued that these mixed results on the effects of collaborative agreements may be due to the omitted indirect effects of firms' absorptive capacity (Escribano, Fosfuri and Tribo, 2009; Tsai & Hsieh, 2009; Tsai and Wang, 2009). The availability of external sources of knowledge does not itself imply that firms can easily use them; they need a certain level of absorptive capacity in order to identify, adopt and apply this external knowledge (Cohen and Levinthal, 1990). Although there is an extensive literature on the direct impact of firms' absorptive capacity and the complementarities between firms' own R&D and external R&D sources (Cassiman and Veugelers 2006; Cassiman and Veugelers 2009; Cassiman and Veugelers 1999), there are few studies that take into account the impact of interactions between firms' absorptive capacity and external sources, which may explain the mixed empirical results.

Overall, the evidence reviewed suggests that UK firms benefit from external knowledge sources. The main sources of external knowledge are identified as suppliers and customers from the literature. Firms that are more engaged in collaborative agreements are more likely to innovate. The role of universities, however, is more ambiguous and there is less consensus regarding their impact on firm productivity. The review highlights the importance of absorptive capacity in benefiting from external knowledge assets.

3.2 Measuring Spillovers

There are two broad branches of literature concerning the measurement and impact of knowledge spillovers. The first one consists in introducing an external knowledge measure in a standard production function, alongside the traditional inputs such as capital and labour. This so-called "trade-growth" approach is based on works from Krugman (1979) and Grossman and Helpman (1991) which define knowledge and its externalities as the key determinants of growth and international trade. The analysis is conducted either at the firm level, or at the more aggregated sector or country level, and aims to assess the impact of the external knowledge on the total factor productivity of units considered, by emphasising the geographical aspect. Different results are obtained depending on the channel considered, i.e. international trade, foreign direct investment (FDI) or technology payments.

The second branch of literature is the knowledge production function (KPF) framework, initiated by Griliches (1979; 1986). This approach focuses on knowledge spillovers in a technological space. From an empirical perspective, it assesses their impact on the production of knowledge, often measured by patents.

1) Knowledge Production Function

Several specifications of the knowledge production function have been investigated in the empirical literature (See among others, Blundell, Windmeijer, and Griffith, 1995; Hausman, Hall, and Griliches, 1986; Pakes and Griliches, 1984). The role of spillovers in knowledge production function framework is proxied by the amount of R&D conducted by other firms/sectors/countries weighted by some measure of technological and/or geographical proximity. The closer technical and geographic proximity the greater the intensity of potential knowledge flow spillovers between the source and the recipient (Mancusi 2008). The measurement of the weight varies between studies.

Jaffe (1986) is one of the first to estimate the impact of R&D expenditures and technological spillovers on patenting activity of US firms. He shows that firms’ own R&D investments as well as other firms’ R&D investments in the industry will have a positive impact on patenting activity, the effect of external R&D depending on the technological proximity between firms (Adam Jaffe 1986). This positive effects is corroborated by Cincera (1997) using the same methodology on patent counts. In the same line with Jaffe, Brendstetter (2006) assess the impact of firms’ own R&D, and domestic and foreign spillovers in American and Japanese firms and finds that firms benefit from their own R&D investments as well as national R&D however the evidence for international spillovers is limited. Los and Verspagen (2000) compare different weights (based on input/output tables, patent citations, and trade flows) and conclude for a positive impact of R&D spillovers, this result being robust to the different specifications.

Employing patent statistics as an output indicator of innovation allows patent citations to reflect the process of knowledge diffusion. Like scientific papers, patent documents contain references to earlier patent documents; we can then assume a knowledge flow from the cited patent to the citing one. Jaffe, Trajtenberg and Henderson (1993) and Jaffe and Trajtenberg (1996) have been the first to consider patent citations as a paper trail of knowledge flows. The patent citations indicator has been widely used to measure the spatial distribution of the technological diffusion (Jaffe and Trajtenberg 1996; Maurseth and Verspagen 2002; Bottazzi and Peri 2003; Thompson and Fox-Kean 2005).

Using patent citations to trace knowledge flows, and patents to measure innovation activities, Malerba et al. (2007) find that alongside international spillovers, intra-sectoral spillovers are also a very important determinant of innovation in six large countries (France,Germany, Italy, Japan, UK and US) over the period 1981-1995.

The only study to our knowledge to estimate the impact of innovative activities on inter-industry total factor productivity for the UK is Sterlacchini (1989). Exploring the performance of British manufacturing industries in terms of productivity growth across various periods between 1954 and 1984, estimate the rate of return for firms' own R&D activities to be around 12-20%, whereas external R&D ranges between 15-35% (Sterlacchini 1989).

Finally, the number of studies which combine patent citations with trade and investment flow is rather scarce. Sjöholm (1996) finds a correlation between Swedish patent citations and bilateral imports, suggesting that imports contribute to international knowledge spillovers. Globerman, Kokko and Sjöholm (2000) evaluate technology sourcing of Swedish multinational and small and medium sized enterprises (SME) and find that outward FDI increases citations. Brandstetter (2006) analyzes FDI and citation flows between USA and Japan, and shows a positive impact of FDI on knowledge spillovers. Using micro level data on French firms, MacGarvie (2005b) finds that both importers and exporters learn more from foreign technology then firms not involved in international trade. At a regional level, Peri (2005) compares knowledge and trade flows, and concludes that there is a lesser impact of distance on the former. We explore spillovers via trade and investments flows in more detail in the next section.

2) Trade Growth Approach

Endogenous growth theory predicts that growth rates of countries are related through international trade linkages and associated embodied and disembodied knowledge spillovers (Grossman and Helpman 1991). As mentioned earlier, knowledge is inherently non-rival in its use, and hence its creation and diffusion are likely to lead spillovers and increasing returns. It is this non-rival property of knowledge that is at the heart of the theoretical models that predict endogenous growth from research and development (R&D) investments (Aghion and Howitt 1998; Romer 1990; Grossman and Helpman 1991). In this context, the development of a country depends heavily on its knowledge capital, which in turn is determined by the rate of national innovation and international technology diffusion. Three mechanisms have been identified to assess the impact of trade openness on technology diffusion (Redding and Proudman 1998): the degree of international openness can affect the rate of domestic innovation, the quantity of transferred technology or the adoption rate of more advanced countries' technologies.

At the firm level, the empirical literature has long focused on the role of exports, given the exporting firms' high productivity growth (Aw and Hwang 1995; Clerides, Lach, and Tybout 1998; Bernard, Jensen, and Jensen 1999). There are two alternative, although not mutually exclusive explanations of exporters' higher productivity rates (Wagner 2007). The first one points to self-selection which explains that the direction of causality is from productivity to exporting; firms that are more productive are more likely to export. The second explanation relates to learning; knowledge flows from international competitors and buyers and intense competition in international markets improve exporting firms' performance. Firms become more productive because they export. Learning-by-exporting is conceptually very closely related to the notion of spillovers, as firms can benefit from the knowledge in international markets through other channels than their customers.

Before reviewing potential spillover effects of exporting, we first report studies on the characteristics of exporting firms. In the UK, exporting firms are found to pay higher wages, and to be larger and more productive (Greenaway 2004). Controlling for other characteristics that might affect these differences, Greenaway and Kneller report that exporting firms' productivity are on average 8.3 and 11.4 % higher than non-exporting firms (measured by total factor productivity (TFP) or labour productivity, respectively). The difference of size ranges between 3.9 and 6.2, measured by output and employment. In aggregate, exporting firms contribute more to overall UK productivity growth than non-exporting firms (Harris and Li 2008).

While it is difficult to distinguish empirically the direction of causality between exporting and higher productivity, recent evidence on UK firms suggest the existence of some learning effects. For example, Greenaway and Yu (2004) report positive learning effects, although only for younger exporters. On first year of exporting, firms experience a TFP growth rate about 1.6 % higher than non-exporting firms, and a 10 % increase in the export share in the period after entry leads to an additional 2.1 % TFP growth (Girma et al. 2004). Crespi et al. (2008) show that exporters draw information from their buyers when innovating. A recent survey found that around 63.5 % of the UK firms report a positive impact on profitability and 87 % on increased sales from exporting; and 65% report improved products, services, marketing and capacity utilisation, the latter suggesting the existence of learning effects (Kneller and Pisu 2010).

Beyond these spillover effects on exporting firms, exporting can also lead to other productivity externalities or demonstration effects on non-exporting firms (Alvarez and López 2008). So-called "productivity spillovers by exporting", these externalities refer to the effects that exporting firms generate on other domestic and non-exporting firms' performance (Silva, Afonso, and Africano 2012). They can either be positive when non-exporting firms benefit from exporting firms' accumulated knowledge of technology and foreign markets ("demonstration effects"); or negative if there is a higher demand by exporting firms yielding to shortage of specialized inputs ("congestion effects") (Karpaty and Kneller 2010). Greenaway and Kneller (2008) find evidence on productivity spillovers by exporting in the UK; having neighbour exporters and/or being located in high-export intensity regions increase the likelihood of exporting.

Another branch of empirical research, initiated by Coe and Helpman (1995), has analysed the knowledge capital incorporated in imported goods. The impact of these spillovers via imported goods on the host countries' growth has been largely verified (Coe, Helpman, and Hoffmaister 1997; Keller 2000; Lichtenberg and van Pottelsberghe 1996).

From a theoretical perspective, endogenous growth theories provide the "missing link" between openness and growth via knowledge spillovers (Lejour and Nahuis 2001). In this context, knowledge originating in a particular country or region increasingly transcends national boundaries and contributes to the productivity growth of other geographic areas, or at least, reduces duplication of the research effort. International trade can be a source of spillovers through demonstration effects when domestic firms learn the innovative content of imported goods. Below we briefly summarize the empirical results confirming that foreign R&D influences domestic productivity and that the more countries are open to international trade the more they benefit.

Coe and Helpman (1995), Coe et al. (1997) were among the first to estimate a positive and quantitatively large effect of import-weighted foreign research and development investments (R&D). In a sample of 22 developed countries, the authors have estimated that roughly a quarter of the benefits from R&D in G-7 countries (Canada, France, Germany, Italy, Japan, the UK and the US) were due to their trading partners. Coe and Helpman's framework has been criticised (see Lichtenberg and van Pottelsberghe de la Potterie (1996) and Keller (1998)) and extended by including country characteristics (Keller 2000; Coe, Helpman, and Hoffmaister 2009), geographic characteristics such as distance and language (Keller 2002), by restricting trade to capital goods (Xu and Wang 1999), by using different estimation techniques (Kao and Chen 1999; Coe, Helpman, and Hoffmaister 2009) or by assessing indirect R&D spillovers (Lumenga-Neso, Olarreaga, and Schiff 2005). These different empirical studies, despite their different empirical specifications, suggest the existence of positive spillovers effects.

Previous studies have shown that technology diffusion via trade flows varies considerably between industries, high-technology intensive industries being more likely to receive R&D spillovers (Acharya and Keller 2009; Keller and Yeaple 2009). Furthermore, industry variations are estimated to be more important than country variations when analysing international R&D spillovers (Acharya and Keller 2009). The average effect across industries is mainly driven by aircraft, chemicals, communication equipment, computers and drug industries.
An empirical analysis on 14 manufacturing industries in the UK during 1970-1992 shows that R&D affects rates of UK productivity growth through innovation, while international trade facilitates the transfer of technology (Cameron, Proudman, and Redding 2005). Based on a very detailed analysis of international technology transfer through imports in Acharya and Keller (2009), at the average industry level, international R&D spillovers are found to be more important than the domestic technology spending in the UK (as in many industrialized countries). UK productivity is shown to be particularly affected by Japanese R&D compared to US and Germany. A 10% increase in domestic R&D translates on average into about 0.5% higher productivity, whereas the impact of international R&D spillovers ranges from 1.4 to 3.8% (Acharya and Keller 2009).

In the same context, multinational firms and foreign direct investment flows have also been considered as a channel of technology transfer to the host countries. Technology is transferred through FDI by three main mechanisms; demonstration effects, labour mobility and linkages between buyers and suppliers. There are extensive surveys of the literature on FDI spillovers; see surveys by Blomström and Kokko (1999), Cincera and van Pottelsberghe (2001), Saggi (2002), Gorg and Greenaway (2004), Smeets (2008), Keller (2009) and Harris (2009) among others. The empirical literature is however ambiguous. While there seems to be evidence of spillover effects of outward FDI (Hanel 1993; van Pottelsberghe, Lichtenberg, and Potterie 2001) as well as inward FDI (Findlay 1978; Blomstrom 1986; Borensztein, De Gregorio, and Lee 1998; Balasubramanyam, Salisu, and Sapsford 1996), there's no consensus about its magnitude (See Haddad and Harrison (1993) and Aitken and Harrison (1999) for examples of the negative or null impact of FDI on home countries).

Before reviewing the evidence for the UK, we will first present different types of FDI spillovers and sum up briefly the extensive research on their determinants, by referring to two recent meta-analyses of FDI spillovers[1].

The literature distinguishes between horizontal and vertical FDI spillovers. The effects of foreign investment on domestic firms in the same sector are called horizontal spillovers. On the other hand, vertical spillovers refer to the effect of FDI on domestic firms that are in suppliers and customer sectors. On average, horizontal spillovers are found to be negligible but their magnitude depends on a number of characteristics of source and host countries, domestic firms and type of investments; technology gap between foreign investors and domestic firms, the trade openness and the better protection of intellectual property rights decrease the impact of horizontal spillovers, whereas higher human capital and joint-ventures (rather than fully foreign-owned projects) are associated with larger spillovers (Iršová and Havránek 2012). Regarding to vertical spillovers, on average spillovers to suppliers (backward spillovers) are economically significant, whereas the spillovers to buyers (forward spillovers) are statistically significant but small; openness to international trade, smaller technological gap and geographic distance is found to increase the magnitude of vertical spillovers (Havranek and Irsova 2011).

Here, we will draw on recent work of Harris (2009), and Gorg and Greenaway (2004) and Haskel et al. (2002) who provide an extensive analysis of FDI spillovers in the UK. An overview of the previous empirical research on different types of FDI spillovers in the UK is presented in the Annex, Table A2.

Before discussing any potential spillovers effect from FDI, it has to be established that FDI plants operating in the UK are performing better than the domestic plants. Although the first study exploring the productivity levels in the motor vehicle industry did find significant differences between foreign-owned establishments and domestic firms (Griffith, 1999; 2001), it has been shown subsequently that this result may be due to sampling problems (i.e. data was biased towards larger establishments) (Harris 2002). Taking into account this bias, Harris showed that US and EU-owned plants were on average 21-26 % more productive than UK-owned plants. In a more extensive study on 20 4-digit manufacturing industries, Harris and Robinson (2003) also corroborate this result, although they did not find a clear productivity advantage for EU-owned plants. Using a different and more recent data, Harris and Li (2007) demonstrate that FDI plants are generally better than non-exporting domestic firms, although this is not the case for certain regions of the UK such as Northern Ireland. Distinguishing between US and British-owned plants, Criscuolo and Martin (2009) find that US-owned plants have a significant productivity advantage in the UK, compared to both British and other foreign-owned multinationals.

Having established a higher productivity rate for at least some of the foreign-owned plants does not necessarily imply positive spillover effects from FDI for UK firms. Haskel et al. (2002) report that at the industry level, a 10 percentage-point increase in the foreign presence boost domestic plants' total factor productivity by about 0.5 percent. On the other hand, Harris and Robinson (2004) evaluate backward, forward, intra-industry and agglomeration spillovers over 20 manufacturing industries and do not find any clear pattern for benefiting from spillovers. These mixed results may be due to different methodologies, samples and/or periods analysed by different authors (Haskel et al. Considers the period between 1973-1992, whereas Harris and Robinson study 1990-1998), but also domestic firms' technological abilities vis-a-vis foreign-owned firms.

The differences in terms of productivity, technological ability or absorptive capacity between foreign-owned and domestic firms are considered as crucial in spillovers literature. It has been argued that the potential for catch-up depends positively on the difference level between leader and follower (Findlay 1978). This difference between two firms (or countries) is referred as the technology or the efficiency gap. However, The role of technology gap is rather unclear (Sjoholm 1999). According to some studies, for a given amount of foreign presence, the spillovers are larger, the larger the technology gap (Fagerberg 1994; Fagerberg 1995). On the other hand, the large technology gaps may constitute an obstacle for technology transfer (Lapan and Bardhan, 1958).

In the UK, empirical studies (Girma and Wakelin 2000; Görg and Greenaway 2004; Girma and Görg 2007; Haskel, Pereira, and Slaughter 2002) have pointed to absorptive capacity of domestic firms, and to technology (or efficiency) gap between foreign-owned firms and the domestic firms. Indeed, the concept of technology (or efficiency) gap is closely related to the concept of absorptive capacity. Girma (2005) finds that firms with a lower technology gap (i.e. difference between firms' productivity level and the industry frontier productivity level) of 10 percent or less benefit from FDI spillovers. These effects seem to be closely related to industrial characteristics; firms located in high-technology sectors may gain from FDI even if they have a larger technology gap, whilst firms with low technology gaps in low-technology sectors may suffer from foreign presence (Girma, Greenaway, and Wakelin 2001). This finding suggests that in presence of high absorptive capacity, the level of technology gap does not matter much, however for firms with a low level of initial productivity; the foreign presence may be detrimental. Then again, Haskel et al. (2002) show that larger gaps lead to higher spillovers when measuring the gap relative to the distribution of three measures of performance (namely total employment, size and skill intensity). Girma and Gorg (2003) suggests a non-linear relationship between absorptive capacity and productivity spillovers from FDI, only firms with some level of absorptive capacity will benefit from foreign presence. Firms' absorptive capacity relative to foreign-owned firms may also be proxied by their engagement in international markets. Exporting firms are supposed to have a higher absorptive capacity than non-exporting firms (see the section above). Domestic exporters are found to experience positive intra-industry spillovers, whereas non-exporters do not; a 1 percentage point increase in horizontal FDI increases 1.2% the productivity of an exporter with a median level of absorptive capacity (Girma, Görg, and Pisu 2008). However, these findings depend also on the type of FDI; while domestic-market oriented vertical FDI results on positive spillovers on both exporting and non-exporting domestic firms, export-oriented FDI has a negative effect (Girma, Görg, and Pisu 2008). Export-oriented FDI can also increase the likelihood of domestic firms to engage in international markets as well as the export intensity of exporting firms (Kneller and Pisu 2007).

Another characteristic of foreign FDI that should also be taken into account is its orientation; whether foreign firms enter the domestic market to exploit their comparative advantage in the host country, or for locational advantages, to access technology that is generated by host country firms, known as “technology sourcing”. In case of technology sourcing FDI, the extent of productivity spillovers may be limited, or may even occur in the other direction, i.e. from domestic to foreign enterprises (Driffield and Love 2005). This type if FDI is more likely to take place in industrialised countries (van Pottelsberghe de la Potterie and Lichtenberg 2001). Driffield and Love (2005) show that foreign sector in UK manufacturing benefits from productivity spillovers in knowledge-intensive industries, both from UK-owned firms and other foreign-owned firms. Driffield and Love (2007) explore in detail the motivation for foreign FDI in the UK, and identify four types of FDI; technology sourcing/location advantages; technology sourcing, efficiency sourcing and ownership advantage. Ownership advantages refer to the classic case where a firm has some competitive advantages and will prefer to set up production facilities through FDI than exporting due to property rights protection (Dunning 1977; Dunning 1981; Cantwell 1989). Technology sourcing corresponds to the model of FDI in which the motivation is to access and transfer host country’s technological advantages (Fosfuri and Motta, 1999). Location advantages refer to FDI decisions motivated by country-specific phenomenon, generally factor costs differentials. In the case of the UK, domestic firms only gain from FDI motivated by ownership advantages; technology-sourcing inward FDI does not lead to productivity spillovers (Driffield and Love 2007). This perverse effect of technology sourcing FDI are also corroborated by the findings on engineering sector where UK has an advantage relative over FDI-source countries (Girma and Görg 2007; Girma and Görg 2003).

Overall, the surveyed evidence indicates positive spillovers via trade flows, however the evidence of positive effect of FDI spillovers on UK domestic firms is, at its best, mixed (See also Table A2 in the Annex). Attracting foreign direct investment does not lead to higher productivity in local firms. Positive effects depend on a number of characteristics of both local and foreign-owned firms. The absorptive capacity and the technology or efficiency gap between firms is crucial, but also the foreign firms’ orientation. Given that UK has a certain level of comparative advantages in number of sectors; it is very likely that foreign firms’ main objectives would be technology outsourcing, exactly the type of FDI that is potentially more prone to negative spillovers. The negative spillovers may occur when domestic firms with low absorptive capacity are exposed to competition effects; an increase in their costs due to increased market share of foreign-owned firms. Less efficient firms risk being crowded-out because of FDI competition. On the other hand, as stressed in the first section, the access to external sources of knowledge is crucial for firm performance, hence there might be other mechanisms, generated by geographic proximity, via which the presence of foreign firms will be beneficial to the UK economy. The next section will focus on this geographic dimension.

Summary of the findings:

- In order to remain competitive, it is no longer enough to rely on internal knowledge assets, there is need to be open to external sources.
- The main sources of external knowledge in the UK are suppliers and customers, whereas universities are the least frequently cited sources.
- Firms that are engaged in collaborative agreements are more likely to innovate, however this positive impact does not always correspond to higher productivity.
- The review highlights the importance of absorptive capacity in benefiting from external knowledge assets.
- Firms can also benefit from external knowledge without engaging in collaborative agreements or economic transitions via the spillover effects.
- There are two broad branches of literature that measure the impact of spillovers; knowledge production function and trade-growth approach.
- Using the knowledge production function, the rate of return for firms' own R&D activities has been estimated to be around 12-20%, whereas external knowledge ranges between 15-35%.
- Trade-growth approach focuses on the role of international trade in transmitting knowledge spillovers.
- In the UK, 63.5% of the firms report a positive impact on profitability and 87% on increased sales from exporting, and 65% report improved products, services, marketing and capacity utilisations.
- While R&D affects rates of UK productivity through innovation, international trade is found to facilitate the transfer of technology, and international R&D spillovers are found to be more important than the domestic technology spending.
- Empirical evidence on positive FDI spillovers is, however, mixed. Positive effects depend on the characteristics of both local and foreign-owned firms.

4. The Spatial Dimension and Mechanisms of Spillovers

The idea of positive externalities of spatial proximity, or agglomeration economies is not new; Marshall (1890) in his "industrial district" argument asserts that the spatial concentration of production reduces the production costs of the individual firms in the cluster. The literature distinguishes between two different types of agglomeration economies; location externalities and urbanization externalities. The location externalities are also called MAR-spillovers, named after Marshall (1890), Arrow (1962) and Romer (1986), and are defined as spillovers occurring between agents within an industry (Glaeser et al. 1992). An example of MAR-spillovers is the concentration of suppliers of semiconductors and related technologies in Silicon Valley (Audretsch and Feldman 1994). The urbanization externalities, on the other hand, take into account the diversity in an agglomeration. Also called Jacobian-spillovers, this type of spillovers occur between different industries (Jacobs 1969; Jacobs 1984). We can say that while MAR-spillovers exploit regional economies of scale, Jacobian-spillovers exploit the regional economies of scope (Beaudry and Schiffauerova, 2009).

In the UK, recent studies find positive localization and urbanization externalities at the firm level using FAME Data (Graham 2009; Graham et al. 2010). On the other hand, using ARD Database, Overman et al. (2009) show positive urbanization externalities on total factor productivity growth, but negative localisation externalities. Exploring the effects of being located in cities, both Overman et al. (2009) and Harris and Moffat (2012c) find that firms in the Southeast of England and London tend to have higher productivity than firms located elsewhere. Plants located in "core" cities are found to perform better than plants in the same region outside of these cities, but overall there is no strong evidence that being located in British cities is encouraging growth (Harris and Moffat 2012c). The city-region with the highest productivity outside of London is Bristol (Overman, Gibbons, and Tucci 2009; Harris and Moffat 2012c).

In a study that explores the determinants of FDI location in UK regions using UK Trade and Investment (UKTI) dataset between 1997-2003, Dimitropoulou et al. (2013) show that London is qualitatively different to the other UK regions as it attracts new investment projects. The authors also find that localization is far more important in attracting inward FDI projects than urbanization externalities at the regional level (Dimitropoulou et al., 2013). Using the same dataset between 1985-2000, Wren and Jones (2012) highlight the importance of agglomeration economies in determining FDI location at the regional level. The authors conclude that regional policy can alter this location pattern, however this effect is not self-sustaining; FDI reverts to its earlier pattern once the policy is related (Wren and Jones 2012, p:282).

More recently, a growing literature has been focusing on various concepts related to the spatial dimension of technical change (for an extensive survey of regional growth models, see Harris (2011)). Whether it is called clusters (Porter 2003), learning regions (Florida 1995), local innovative milieu (Maillat 1998; Camagni 2005), local innovation systems (Cooke, Gomez Uranga, and Etxebarria 1997), or local buzz (Storper and Venables 2004; Bathelt, Malmberg, and Maskell 2004), the main idea posits that regions possessing certain tangible and intangible assets experience superior performance. Due to the fundamental role that geographical proximity among agents plays in mediating the processes of knowledge creation, transmission and appropriation certain regions accumulate intangible assets and tacit knowledge (Breschi 1998). These intangible assets are hard to grasp for non-local firms outside the regional innovation system. In order to reap fully the benefits of local buzz, co-location rather than occasional interludes of face-to-face contact is required (Kramer and Diez 2012; Boschma and Frenken 2009). Buzz itself is a complex concept but has been defined as consisting of specific information flows, intended and unanticipated learning processes, mutual understanding of new knowledge, shared cultural traditions and habits; and one can benefit from and contribute to the buzz by just “being there” (Storper and Venables 2004; Bathelt, Malmberg, and Maskell 2004; Gertler 2003; Florida 2002).

The literature has identified three mechanisms that may produce a skewed spatial distribution of innovation activities. These are agglomeration economies, knowledge spillovers and technological diversity. In this review we are mainly interested in local knowledge spillovers, considered as the mechanism that facilitates the transmission and the acquisition of tacit and complex knowledge. The main argument is that local firms competing in the same industry or collaborating across related industries will generate processes promoting learning and innovation. This is because spatial proximity carries with it, among other things, the potential for intensified face to face interaction, short cognitive distance, common language, trustful relations between various actors, easy observation and immediate comparison of actions and outcomes (Malmberg and Maskell 2002).

However, the concept of local knowledge spillovers has been criticised as being no more than a “black box” (Breschi and Lissoni 2001a; Doring and Schnellenbach 2006). Some studies question how much of the clustering is due to local knowledge spillovers. Empirical evidence on the exact mechanism via which the knowledge is transmitted is still lacking (for a critical survey, see Breschi and Lissoni (2001a; 2001b)). The main arguments identified against the view that tacit knowledge requires spatial proximity are summarised as follows by Breschi and Lissoni:

- Knowledge sharing is less likely in industries with a rapid pace of technological change (Zucker, Darby, and Armstrong 1998).
- Knowledge sharing amongst previous colleagues is more likely to concern small ideas, and not strategic knowledge given the risk of a competitive backlash for the disclosing companies (Appleyard 1996).
- Inter-personal channels of communication are relatively more important for sharing knowledge with customers than for sharing knowledge with competitors. Furthermore, friendship does not increase the transfer of specific information (Schrader 1991).
- Inter-personal knowledge sharing does not necessarily requires physical proximity (Lakhani and Hippel 2003).

- Tacit knowledge can, moreover, be transferred by formal means of communications such as mails, scientific articles or public conferences (Breschi and Lissoni 2001b, 262). Malmberg and Power (2005) argue that there is limited evidence on inter-firm transactions and collaboration in local clusters. Successful and innovative firms use a mixture of local and extra-local collaborations and connections, and that one cannot fully function without the other (Simmie 2004; Malmberg and Power 2005). The channels used for extra-local interactions are referred as "pipelines" in the literature (Owen-Smith and Powell 2004). Knowledge flows through pipelines are not automatic, their establishment and maintenance require actions by firms to predesign and plan in advance (Bathelt, Malmberg, and Maskell 2004).
- It is important to note that, physical proximity does not imply social proximity, which has more dimensions than the spatial one. This argument is also picked up in Boschma (2005), who claims that spatial proximity on its own is neither necessary, nor sufficient for learning. However, it may facilitate learning by strengthening the other dimensions of proximity, namely cognitive, organizational, social and institutional proximities (Boschma 2005). Boschma also argues that there is non-linear relationship between learning, innovation and proximity. This is termed proximity paradox, too much and too little proximity are detrimental to learning and innovation (Boschma 2005; Boschma and Martin 2010; Broekel and Boschma 2011). Based on Nooteboom's work on optimal cognitive distance (Nooteboom 2000), it has been argued that an "optimal" proximity or combination of proximities may exist between agents (Boschma and Martin 2010; Broekel and Boschma 2011).

We can now focus on the empirical evidence for the UK. First, we establish whether there are positive cluster effects in the UK. Evidence of positive cluster effects implies that spillovers may exist. We can then focus on studies that explore mechanisms of knowledge diffusion which induce spillovers.

Baptista and Swann (1998) evaluate the innovative behaviour of UK manufacturing firms and find that firms located in industrial clusters or regions are more likely to innovate than firms outside these regions. In a comparative study of UK and US computer industries, the authors also find that firm growth is fostered by the strong presence of firms in the same sector, suggesting intra-industry knowledge spillovers (Baptista and Swann 1999). These positive clustering effects have been confirmed for other sectors such as biotechnology (Swann and Prevezer 1996), broadcasting (Cook, Pandit, and Swann 2001), and aerospace (Beaudry 2001). Beaudry and Swann (2001) studied 137,816 UK firms in 57 industries and found that firms grew faster in clusters, especially in the finance, computer, motor, aerospace, and communications manufacturing industries.

Although they indicate a positive effect of geographical clusters, these studies do not shed light on the particular mechanisms through which knowledge flows. There are, however, a small number of mainly qualitative studies that explore particular clusters in the UK that we can draw upon. Henry and Pinch (2000; 1999) study the Motor Sport Valley, home of the British motor sport industry, and identify rapid and continual transfer of personnel, high rates of firm turnover, transactions with suppliers, as well as gossip, rumours and spying as channels of knowledge diffusion. They report that the leakage of knowledge is endemic throughout the industry, but it is seen as part of the high rate of diffusion of innovation across the firms in the sector. As a result, the churning of personnel and sharing suppliers raise the knowledge base of the industry as a whole within the region (Henry and Pinch 2000, 9). In the motor sport industry, it seems that it is the desire to be close to the community of knowledge, than the need to be close to specialist suppliers which generates knowledge.

May et al. (2001) focus on the clustering of the high-fidelity industry in South East England and find also that the main mechanisms of knowledge flows are the transfer of key personnel, a dense network of personal contacts and informal links. However, the authors stress that the innovation process is more closed than in the motor sport industry. Although a lack of horizontal collaboration between firms is noted, innovation in the high-fidelity industry is found to be supported by an increasing degree of mutual learning. There is a large amount of vertical collaboration between firms and their specialist suppliers, but only one third are local.

These local collaborations seem to be preferred by smaller firms, as confirmed by Freel (2003), in a study of 597 UK manufacturing firms. Larger SMEs and firms that are engaged in radical innovation tend to get involved in more distant networks (Freel 2003). Bennett et al. (2001) explore the influence of location on use of external advice and collaboration. They show that location has a very small impact once the firm and sectoral-level characteristics have been taken into account. Regarding the use of private-sector advisers such as accountants or consultants and vertical collaborations, the intensity of use does not vary significantly with location in most cases. Only the input of business friends and relatives is strongly constrained by location. On the other hand, based on interviews with software and IT developers and electronics SMEs in Oxfordshire and Berkshire, Romijn and Albu (2002) highlight the importance of interactions with suppliers, private sector providers, training institutes and local support organisations in fostering innovation. Geographic proximity is found to be of particular importance for radical innovations. The authors also draw attention to the regional science base; firms with strong interactions with research laboratories and universities are more likely to have more original and/or complex innovations (Romijn and Albu 2002).

The role of universities and industry-university relationships has been extensively studied, especially with regards to Cambridge and Oxford high-tech clusters. Although there is evidence of networked economies in both regions, the universities are found to have played different roles; in the Cambridge model the University plays an instrumental role, while in the Oxford model there is a vertical division of labour (Lawton Smith et al. 2001). High-technology SMEs in Cambridge show a greater propensity to form close inter-firm relations than do high-technology SMEs in Oxford, but the latter attach a greater importance to the local links (Lawton Smith et al. 2001). Lawton-Smith (2003), in a study on the set-up of Oxford high-tech agglomeration, shows how the local networks were crucial in providing the right local governance structures, that helped to launch the development of the cluster. Rather than technological learning or innovation, the collaboration between actors laid the foundations for sectoral development. However, in the early stages of Cambridge high-tech agglomeration, it has been suggested that dynamic local interaction was at best embryonic and that many Cambridge firms had to rely on overseas markets without benefiting from significant domestic advantages, except in biotechnology (Garnsey and Cannon-Brookes 1993, 200). Yet, later studies highlight the importance of local interaction and knowledge flows between firms. The critical mass of high-tech activities led the emergence of an informal investor community and the spontaneous emergence of an institutional support system (Keeble et al. 1999). The success of Cambridge high-tech agglomeration include clustering stimulated by serial spin-outs from originator firms, the rise of local suppliers, the emergence of specialist labour markets and the attraction of venture capital; all facilitated by social networks diffusing knowledge (Elizabeth Garnsey and Heffernan 2005). A recent study investigating R&D workers' experience in the Cambridge IT Cluster also shows that the main advantage of the cluster is the labour market advantages and the global brand of Cambridge (Huber 2011). However, nearly two third of the R&D workers "do not see a real knowledge benefit" for their work to be located in Cambridge (Huber 2011, 121). Personal networks seem instead to be a factor linked to the business knowledge of senior managers.

Labour market advantages are confirmed by Faggian and McCann (2006), who explore the effect of British university graduates on regional innovation. The authors find little or no evidence in favour of direct spillovers between university research and regional innovation, suggesting that research conducted at the universities does not constitute a source of knowledge for local firms. However, they show that the primary role of universities appears to be as a conduit for bringing potential high quality undergraduate human capital into a region (Faggian and McCann 2006).
Looking into a traditional industry, rather than high-tech agglomeration, Watts et al. (2003) focus on the Sheffield metal-working cluster. They find that commodity exchanges between owner-managers and their suppliers are accompanied by embodied transactions, although rather infrequently. Moreover these exchanges are no more extensive or significant than those with suppliers located beyond the cluster. The extent and frequency of the exchanges are driven rather by a business logic than personal affinities (Watts, Wood, and Wardle 2003).

Other studies have focused on creative industries. Drake (2003) analyses how perceived attributes of a location provide inspiration in creative processes. Based on interviews with workers in the craft metalwork and digital design sectors in the UK, locality-based intensive social and cultural activity, referred also as the "buzz", unpredictability or excitement of a locality, is found to be a key source of creativity.

An examination of co-location patterns between creative sectors and other innovative industries such as High-Tech Manufacturing and Knowledge Intensive Business Services (KIBS) shows that advertising and software firms are very often found near both High-Tech Manufacturing businesses and KIBS (Chapain et al. 2010). These co-location patterns may be due to value-chain linkages, knowledge spillovers and/or urban buzz. However, in-depth case studies of clusters of software firms in Wycombe and Slough, film, post-production and visual effects in London (Soho), media production in Cardiff and advertising in Manchester, do not always confirm the existence of knowledge spillovers and local buzz. In the case of Wycombe and Slough, few firms were aware of the existence of a cluster, subsequently there is a very low level of formal and informal interactions, and the internet are found to be the main source of contacts (Chapain et al. 2010). On the other hand, firms in Manchester and Soho are shown to collaborate locally as part of their innovation activities, and to engage in higher levels of informal networking (Chapain et al. 2010). Then again, other studies on the Soho cluster have found that the most important role of the local interaction was the provision of services and labour (Nachum and Keeble 2003b; Nachum and Keeble 2003a). When accessing the local labour market, firms rely on informal personal networks, based on loyalty and friendship, and are made entirely informally, through personal recommendations, referrals by colleagues, and word-of-mouth (Nachum and Keeble 2003b). Labour mobility through freelancers plays a significant role for knowledge diffusion in both Manchester and Soho clusters. This is not the case in Cardiff, because of the non-disclosure agreements (NDAs) that constrain the diffusion of knowledge between TV companies (Chapain et al. 2010). By contrast, the Digital Media firms that supply these TV companies with digital platforms and technology services are found to be more open to collaboration, networking and the use of external sources of innovation, thus also facilitating the knowledge flows across TV production firms (Chapain et al. 2010).

The studies we have reviewed present a mixed picture of local knowledge spillovers. There is some evidence for the importance of labour market dynamics and social interaction at the level of the individual in firms’ and clusters’ knowledge creation processes. However, the positive impact of knowledge spillovers seems to be closely dependent on sectoral and institutional characteristics. There are a number of conclusions we can draw upon reviewed studies. The main mechanism of knowledge diffusion is through the labour mobility. Clusters act as a hub for the attraction for global talents. High-technology clusters are found to be more likely to generate knowledge spillovers. However, the nature of the technology is closely related to the issues of intellectual property. Non-disclosure agreements act as a barrier to the knowledge diffusion through human mobility. The regional science-base and university-industry interactions are also important factors. Geographic proximity seems to facilitate personal interactions, however knowledge flows are not confined to proximate locations; successful firms access knowledge regardless of its geographical location. Local and global networks should not be seen as conflicting, they both have important but different, sometimes complementary roles to play

(Christopherson, Kitson, and Michie 2008). A combination of local buzz and global pipelines appears to be the best for the long-term evolution of clusters (Bathelt et al., 2004; Balland et al., 2010). Successful clusters should enable local firms to be embedded simultaneously in knowledge exchanges at different geographic scales.

Summary of the findings:

- The transmission of knowledge can be encouraged by spatial proximity or agglomeration economies as defined by Marshall (1980).
- The literature distinguishes between two types of agglomeration economies; location externalities and urbanization externalities.
- Empirical evidence shows positive urbanization externalities in the UK, but the impact of location externalities is mixed.
- There is no strong evidence that being located in British cities is encouraging growth.
- However empirical evidence points to a positive effect of clustering on UK firms' growth
- But the positive impact of knowledge spillovers seems to be closely dependent on sectoral and institutional characteristics.
- The main mechanism of knowledge diffusion is through the labour mobility as clusters act as a hub for the attraction for global talents.
- High-technology clusters are found to be more likely to generate knowledge spillovers.
- The regional science-base and university-industry interactions are also important factors.
- Geographic proximity seems to facilitate personal interactions, however knowledge flows are not confined to proximate locations; successful firms access knowledge regardless of its geographical location.

5. Construction of the UKIS-ARD Merged Dataset (2005-2011)

The main data source employed in the empirical analysis draws on recent waves of the UK Innovation Survey (henceforth UKIS). This survey was sent to a nationally representative sample of firms in the UK that employed more than 10 employees, every two years from 2005 (prior to this time it was less frequent). We use the recent 4 waves of the UKIS data covering a nine-year period from 2002-2010, viz. UKIS 2005 (for the 2002-2004 period), UKIS 2007 (for the 2004-2006 period), UKIS 2009 (for the 2006-2008 period), and lastly UKIS 2011 (for the 2008-2010 period).

There were 16,445 firms providing valid responses to the UKIS 2005 survey, 14,872 responses to the UKIS 2007 and 14,281 to the UKIS 2009, achieving a response rate of 58%, 53% and 49% respectively. In the case of UKIS 2011, although 14,342 responses were received, only 9,111 firms provided valid information and thus the real response rate was much lower in this most recent wave. On average, around 30% of all firms in the UKIS survey from 2005-2009 are in the manufacturing sector, including 4,863 firms in UKIS 2005, 4,604 in UKIS 2007 and 3,699 in UKIS 2009. This figure reduces to 2,849 (just under 20%) in UKIS 2011. However, with weighting in place, the proportion of manufacturing firms across all 4 waves becomes more consistent (around 20%).

In particular, we consider the potential sample attrition issue relating to the UKIS 2011 data. The UKIS 2011 questionnaire was sent to some 28,000 enterprises in the UK and responses were received from 14,342 enterprises. However, more than 5,300 respondents failed to provide information on the majority of questions and thus deemed unusable, due to a series of changes in both the sampling (e.g. a larger proportion of respondents new to the survey) and collection procedures (e.g. around half of survey responses collected by telephone interview). Therefore, there are only 9,111 valid cases with information on innovation-related activities (with an attrition rate of 36.5%).

In this instance, appropriate tests need to be undertaken to ascertain that sample attrition bias – a form of selection bias - does not arise as a result of such loss of valid responses. That is, the attrition is random and the final usable sample (of 9,111 enterprises) is unbiased in retaining the characteristics of the original UKIS 2011 sample (of 14,342 enterprises), especially in terms of the core variables of interest in this study.

It follows that an attrition probit model has been estimated to ascertain if the final usable sample of 9,111 firms is representative of the original UKIS 2011 sample. This involved estimating a probit model using the *full* UKIS 2011 sample where the dependent variable is an attrition dummy taking the value of one if the record is included in the final sample (i.e. that contains a valid response) and zero otherwise. The estimation results are presented in Table A3 in the Annex.

Ideally the explanatory variables should include those that are expected to affect attrition rate and any variables that might characterize the survey/interview process; nevertheless, given that most of these variables such as those relating to innovation behaviour contain a large number of missing values, our set of explanatory variables are limited to those covering general firm-level characteristics such as employment, weights, industry and regional dummies. Results reported in Table A3 indicate that 13 variables (i.e. mostly industry and regional dummies) are statistically significant in determining attrition. A likelihood-ratio test was subsequently conducted to test the joint statistical significance of these 13 variables and a chi-square of 106.86 led to the rejection of the null hypothesis of no effect on attrition indicating these variables are statistically significant predictors of attrition and thus attrition is non-random[2]. Therefore, in order to correct for attrition bias, new population weights have been created for the 2011 sample for use throughout the analysis, based on similar stratification criteria to those used by the ONS (i.e. by industry division, region and employment size band).

Most of the descriptive analyses in this report are based on all 4 waves of UKIS data pooled together, i.e. 54,709 observations in total with 15,166 in the manufacturing sector. The UKIS data have also been merged with relevant data from the Annual Respondents Database (ARD) using the Inter Departmental Business Register (IDBR) numbers[3], in order to incorporate additional information on firm-level specific characteristics such as age, output, foreign ownership, geography, enterprise structure.

Summary of main findings:

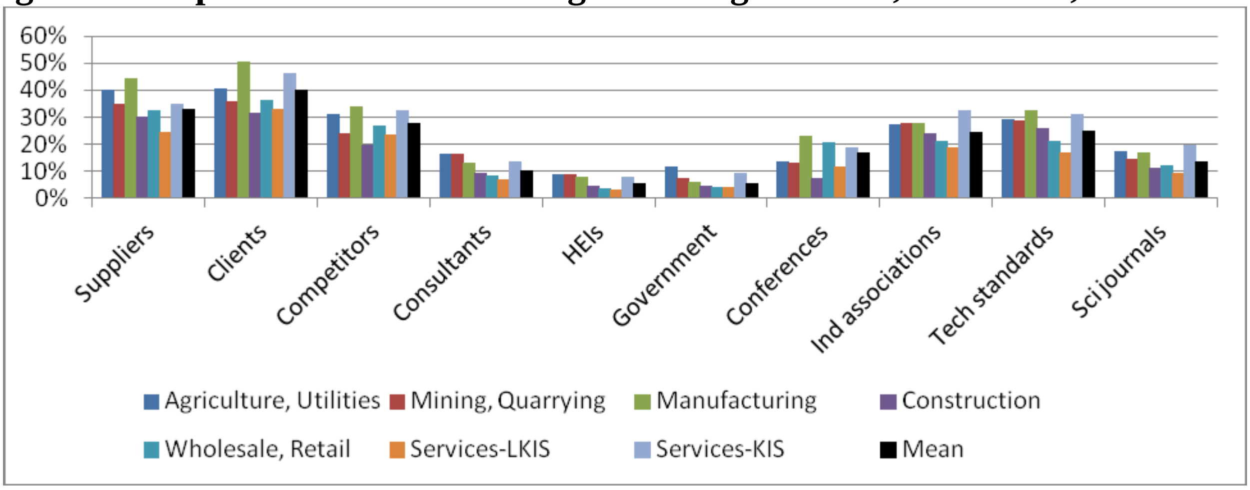
- The empirical analysis presented in this report utilises a linked UKIS-ARD dataset. Most importantly, the recent four waves of the UK Innovation Survey (UKIS) data constitute the main data source covering a nine-year period from 2002-2010.
- There were 16,445 firms providing valid responses to the UKIS 2005 survey, 14,872 responses to the UKIS 2007, 14,281 responses to the UKIS 2009, and only 9,111 responses to the UKIS 2011.
- The potential sample attrition issue relating to the UKIS 2011 data was considered and an attrition probit model was estimated to ascertain if the final usable sample of 9,111 firms is representative of the original sample. The explanatory variables used cover general firm-level characteristics such as employment, weights, industry and regional dummies.
- Results from the attrition probit model indicate that attrition is non-random (i.e. there is evidence of attrition bias) and thus new population weights have been created for the 2011 sample in order to correct for attrition bias.

6. The Use of Knowledge Sources in Innovation by UK Manufacturing Firms

Firms have been asked to identify 10 sources of information/knowledge in their innovation related activities and rate their relative importance, covering the following aspects - [4]

- Market: suppliers of equipment, materials, services or software; clients or customers; competitors or other businesses in the industry; consultants, commercial labs or private R&D institutes;
- Institutional: universities or other HEIs; government or public research institutes;
- Others: conferences, trade fairs, exhibitions; professional and industry associations; technical, industry or service standards; scientific journals and trade/technical publications

Figure 2: Proportion of firms utilising knowledge sources, all sectors, 2002-2010



Data Source: weighted UKIS 2005-2011

Across all sectors[5], Figure 2 shows that clients constituted the most important source of knowledge for innovation activities, with suppliers and competitors also being of great importance. Alongside these market-based sources, a large proportion of firms were also taking advantage of other information sources such as professional and industry associations and technical/industry standards, whereas public institutions (such as government and HEIs) were reported to be least commonly associated with firms' knowledge sourcing for innovation. For instance, engagement with government appeared to be relatively weak, with only Agriculture and Utilities, Mining and Quarrying, Knowledge-Intensive Services (KIS) and Manufacturing sectors showing more than 5 per cent of firms with knowledge links to the government. The story was similar for HEIs with just over 5 per cent of firms (economy wide) stating that they used any information or knowledge from HEIs.

In terms of inter-sectoral differences, manufacturing firms appeared to represent the largest users of knowledge from most sources except consultants, HEIs, government, industry associations and scientific journals or trade publications. Also notably KIS firms seemed to dominate in the use of knowledge from industry associations and scientific journals. Perhaps more surprisingly, consultants were utilised more prevalently within the Agriculture and Utilities, Mining and Quarrying and KIS sectors (vis-à-vis Manufacturing), which may however represent the rather specialised use of experts in many of these sectors.

Table 2: Proportion of firms utilising knowledge sources and ranking, manufacturing industries, 2002-2010

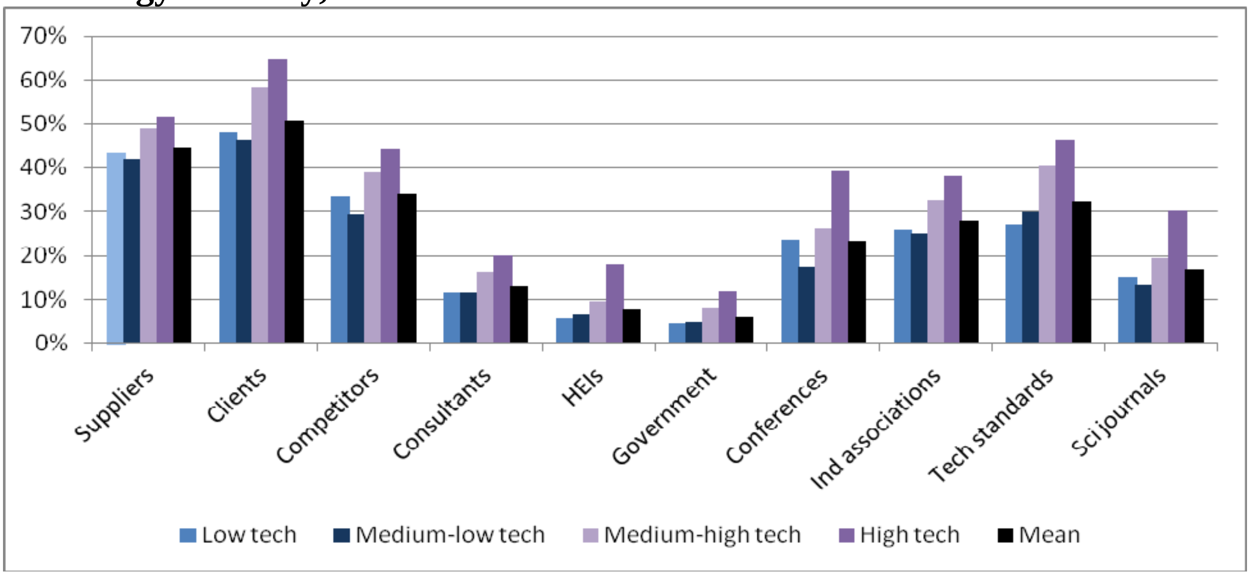
Industry	Suppliers		Clients		Competitors		Consultants		HEIs		Government		Conferences		Ind associations		Tech standards		Sci journals	
Medical etc. instruments	53	*1*	66	*1*	45	*1*	21	*2*	20	*1*	13	*1*	42	*1*	38	*2*	47	*1*	30	*1*
Rubber, Plastic	51	*2*	54	*5*	34	*10*	15	*5*	8	*9*	5	*8*	22	*12*	27	*7*	32	*7*	16	*9*
Electrical machinery	50	*3*	63	*2*	42	*2*	20	*3*	13	*3*	9	*3*	31	*2*	37	*3*	47	*2*	26	*3*
Chemicals	49	*4*	61	*3*	41	*3*	23	*1*	14	*2*	11	*2*	27	*6*	38	*1*	41	*3*	27	*2*
Machinery, Equip	48	*5*	57	*4*	39	*4*	13	*8*	9	*7*	7	*6*	27	*7*	31	*4*	40	*4*	17	*7*
Non-metallic minerals	48	*6*	51	*8*	37	*5*	16	*4*	11	*4*	9	*4*	28	*4*	29	*6*	34	*6*	20	*4*
Motor & Transport eqpt	47	*7*	53	*6*	36	*7*	14	*7*	9	*6*	8	*5*	24	*10*	27	*8*	36	*5*	18	*6*
Publishing, Printing	46	*8*	49	*10*	35	*8*	11	*12*	6	*10*	5	*9*	25	*8*	31	*5*	28	*11*	18	*5*
Paper	45	*9*	45	*11*	32	*11*	12	*11*	6	*12*	3	*14*	18	*13*	24	*12*	29	*9*	14	*11*
Food, Drink	44	*10*	51	*7*	35	*9*	15	*6*	6	*11*	7	*7*	22	*11*	27	*9*	29	*10*	15	*10*
Furniture	43	*11*	50	*9*	36	*6*	11	*12*	5	*13*	5	*9*	28	*5*	24	*11*	27	*14*	17	*8*
Wood products	41	*12*	44	*12*	31	*12*	8	*16*	4	*16*	4	*13*	17	*14*	22	*14*	28	*13*	12	*14*
Textiles	40	*13*	44	*13*	30	*14*	12	*9*	8	*8*	3	*16*	24	*9*	22	*15*	24	*15*	11	*15*
Fabricated metal	39	*14*	43	*14*	26	*15*	9	*15*	5	*14*	4	*11*	14	*16*	23	*13*	28	*12*	11	*16*
Clothing, Leather	37	*15*	43	*15*	30	*13*	10	*14*	5	*14*	3	*14*	29	*3*	17	*16*	22	*16*	14	*11*
Basic metals	34	*16*	42	*16*	25	*16*	12	*10*	10	*5*	4	*12*	16	*15*	27	*9*	30	*8*	13	*13*
Mean	45		51		34		13		8		6		23		28		32		17	

Source: weighted UKIS 2005-2011; figures in italics are rankings

Table 2 above provides a closer look at industries within the manufacturing sector. Suppliers and clients represented main sources of knowledge to around half of manufacturers in Medical etc. Instruments, Electrical Machinery, Chemicals, Rubber and Plastic, Machinery and Equipment, Non-metallic Minerals and lastly Motor and Transport Equipment. Outside these frequently utilised market-based channels, manufacturers in Medical etc; Instruments, Electrical Machinery and Chemicals were also the leading users of knowledge from all other sources (e.g. conferences, industry associations, technical/industry standards and scientific journals). It's worth noting that firms in Medical etc Instruments in particular were most inclined to link their knowledge source to the public sector (i.e. 20 per cent with knowledge ties with HEIs and 13 per cent with government).

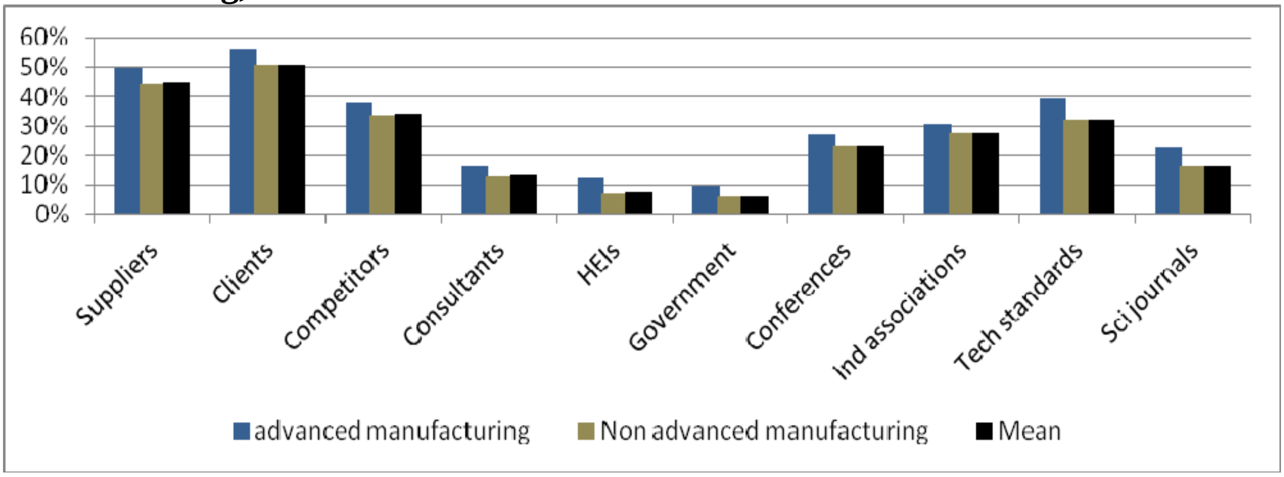
Figure 3 follows OECD's industrial classification[6] to divide manufactures into low tech, medium-low tech, medium-high tech and high tech industries to take a microscopic view of the sector. As might be expected, higher tech manufacturers leveraged knowledge across a wider spectrum of sources at a higher rate than lower tech ones. Also there is an especially notable difference in the percentage of high tech respondents (vis-à-vis low or medium-low tech firms) stating that they utilised knowledge transfer from HEIs, scientific journals and conferences. Overall, there is a clear association between technology intensity and the strength in the utilisation of externally-sourced knowledge amongst manufacturing firms, corroborating the empirical strength of the OECD's classification of industries[7].

Figure 3: Proportion of manufacturing firms utilising knowledge sources by technology intensity, 2002-2010



Source: weighted UKIS 2005-2011

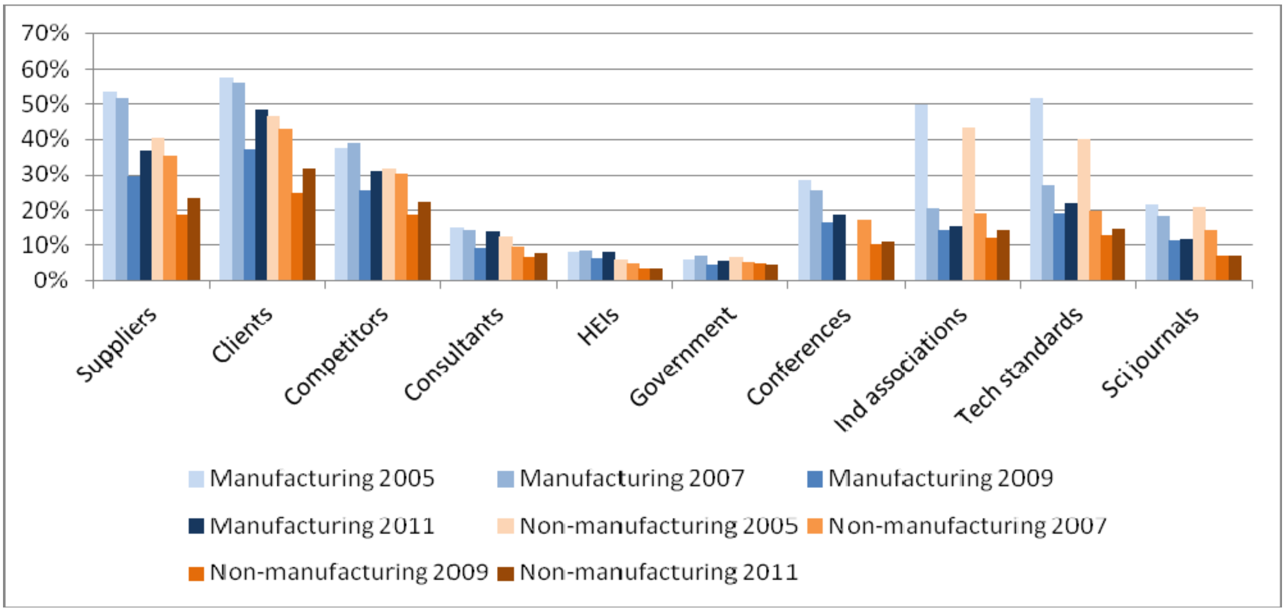
Figure 4: Proportion of firms utilising knowledge sources in advanced manufacturing, 2002-2010



Source: weighted UKIS 2005-2011

Special attention has also been paid to the advanced manufacturing industries that have been identified by the Government to be of particular importance to the UK's industrial strategy, especially aerospace[8], automotive [9] and life sciences[10] (c.f. BIS Economics Paper No. 18 (2012)). Figure 4 shows an unequivocal advantage enjoyed by the advanced manufacturers in their knowledge utilisation: compared with their non-advanced counterparts, a higher proportion of them were able to leverage knowledge across all channels, especially the institutional sources such as government and HEIs.

Figure 5: Proportion of firms utilising knowledge sources over time, manufacturing vs. non-manufacturing, 2002-2010



Source: weighted UKIS 2005-2011

In terms of the evolution of firms' knowledge sourcing behaviour over time, Figure 5 illustrates that there was a general downward trend in the utilisation of knowledge within most categories across the economy, from the 2005 UKIS wave (2002-2004 period) to the 2009 wave (2006-2008 period). The decline seemed most substantial during the 2006-2008 period of economic recession (as evident in the 2009 survey) before an incremental upswing was seen in the most recent 2011 wave (2008-2010 period). The only exception was the case of obtaining knowledge from HEIs and government sources, which remained relatively constant over time. Other than manufacturing firms having a higher utilisation rate of knowledge from all sources vis-à-vis the rest of the economy, the patterns of change over time were broadly comparable.

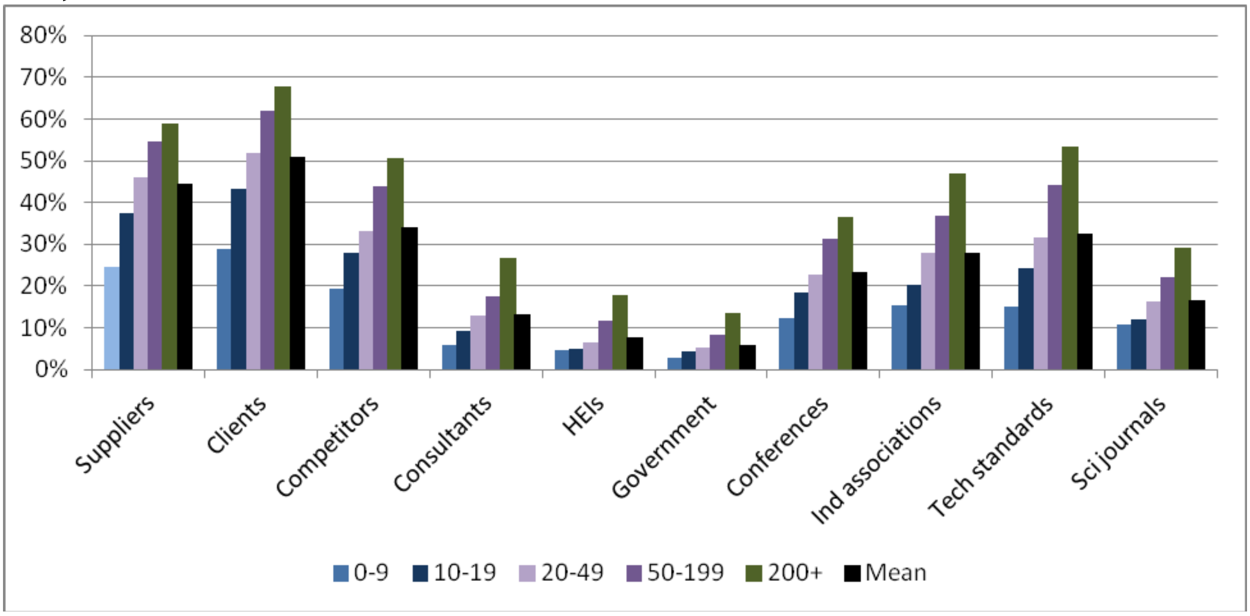
Table 3 provides evidence on the knowledge sources used by UK manufacturers across government office regions (GORs). Again, suppliers, clients and competitors were very important sources for respondents across all UK regions. Knowledge linkage with HEIs was utilised by more than 10 per cent of firms based in Wales and Northern Ireland. And knowledge transfer from government was most prevalent amongst respondents from Northern Ireland (9.2 per cent), Wales (8.5 per cent) and Scotland (7.3 per cent).

Table 3: Proportion of manufacturing firms utilising knowledge sources and ranking, by UK government office region, 2002-2010

GOR regions	Suppliers		Clients		Competitors		Consultants		HEIs		Government		Conferences		Ind associations		Tech standards		Sci journals	
Northern Ireland	50	*1*	54	*3*	40	*1*	18	*1*	11	*2*	9	*1*	30	*1*	20	*12*	25	*12*	20	*1*
Wales	49	*2*	55	*1*	38	*2*	15	*2*	12	*1*	9	*2*	24	*6*	31	*1*	35	*2*	18	*6*
Scotland	48	*3*	53	*5*	34	*5*	13	*7*	8	*4*	7	*3*	26	*2*	31	*2*	36	*1*	19	*3*
South West	47	*4*	51	*6*	33	*10*	13	*6*	6	*12*	6	*5*	23	*7*	30	*4*	33	*6*	17	*7*
Eastern England	46	*5*	55	*1*	36	*3*	14	*3*	8	*6*	7	*4*	25	*3*	30	*3*	34	*3*	20	*2*
North East	46	*5*	50	*7*	33	*9*	14	*5*	8	*5*	6	*5*	21	*10*	28	*8*	32	*8*	18	*5*
York’s & Humber	46	*7*	50	*10*	34	*7*	13	*7*	7	*7*	5	*12*	22	*9*	27	*9*	31	*10*	15	*10*
South East	45	*8*	53	*4*	34	*8*	12	*12*	7	*8*	6	*5*	25	*3*	28	*7*	34	*3*	19	*4*
East Midlands	45	*9*	50	*8*	35	*4*	12	*11*	7	*9*	6	*8*	21	*11*	27	*10*	33	*7*	16	*8*
West Midlands	42	*10*	48	*11*	31	*12*	13	*9*	7	*9*	6	*9*	19	*12*	26	*11*	32	*9*	13	*12*
North West	41	*11*	50	*9*	33	*11*	14	*4*	9	*3*	6	*9*	22	*8*	29	*6*	34	*5*	16	*9*
London	39	*12*	47	*12*	34	*6*	13	*9*	6	*11*	5	*11*	25	*5*	30	*5*	28	*11*	14	*11*
Mean	45		51		34		13		8		6		23		28		32		17	

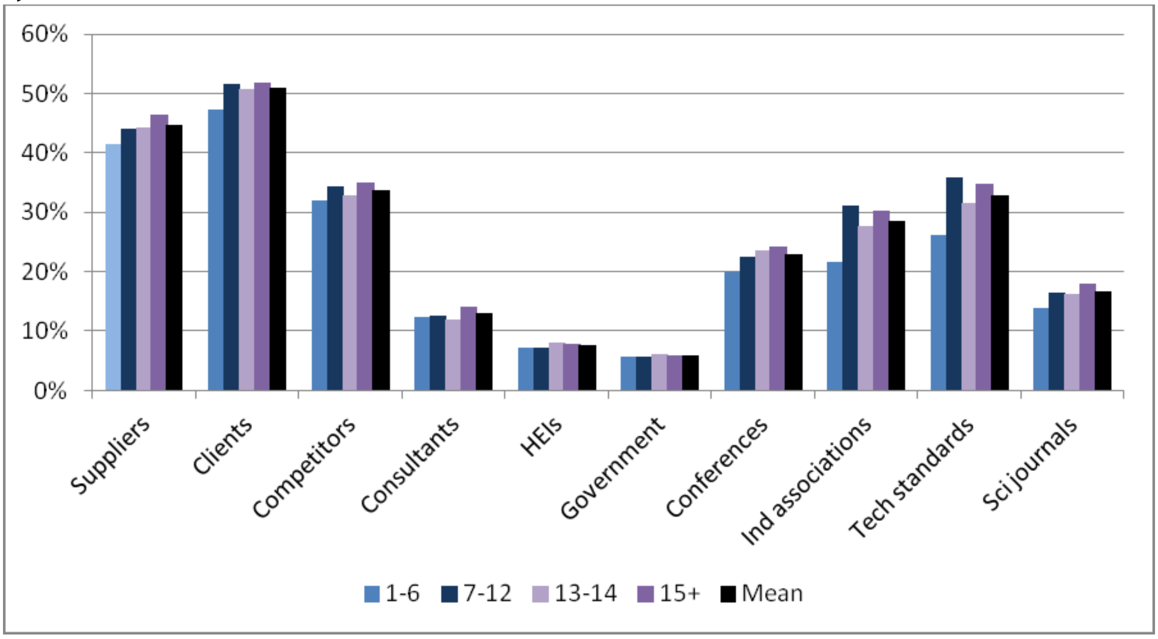
Source: weighted UKIS 2005-2011; figures in italics are rankings

Figure 6: Proportion of manufacturing firms utilising knowledge sources by size band, 2002-2010



Data Source: weighted UKIS 2005-2011

Figure 7: Proportion of manufacturing firms utilising knowledge sources by age band, 2002-2010



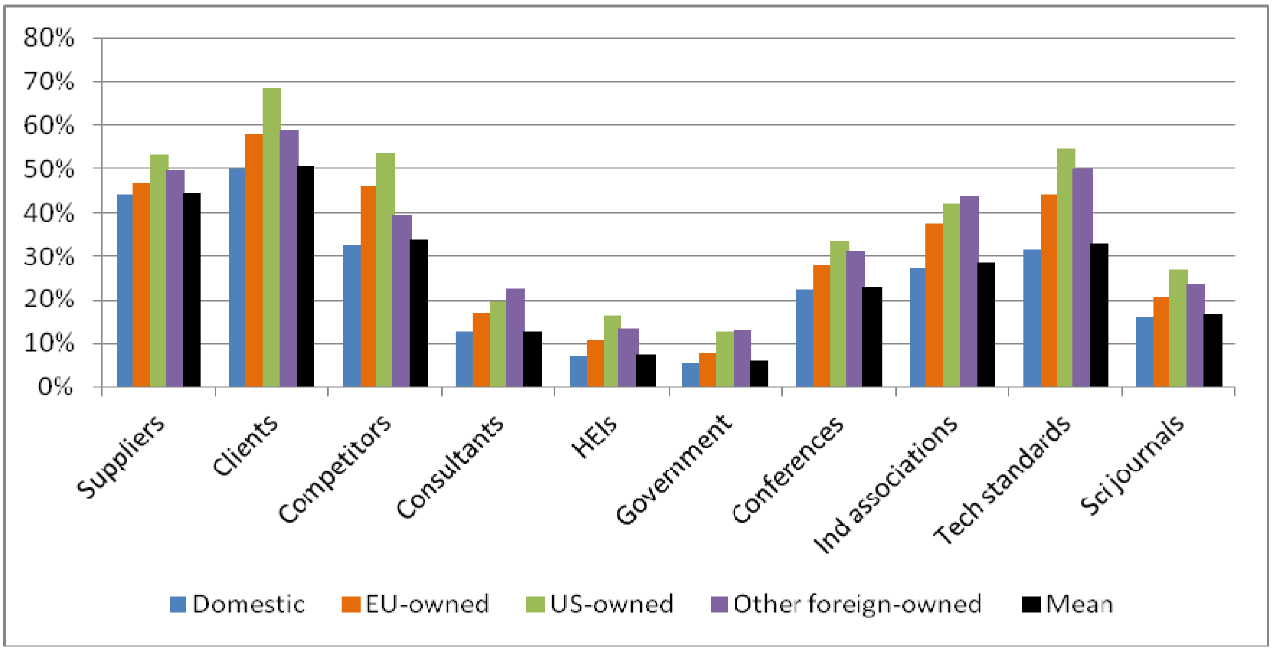
Source: weighted UKIS 2005-2011

Furthermore, Figure 6 suggests that there was a very strong correlation between the size of a manufacturing firm (as measured in employment band) and its orientation of knowledge linkage with external sources. For instance, in most categories, the proportion of firms in the largest size band (i.e. 200+ employees) leveraging from external knowledge sources was twice that of those in the smallest band (i.e. less than 10 employees). In contrast, the relationship between firm age and knowledge sourcing may not be a distinct one. As shown in Figure 7, the utilisation of knowledge seemed to differ little between firms of different age.

Turning next to the effect of foreign ownership, Figure 8 shows that foreign subsidiaries in the UK manufacturing routinely outperformed their indigenous counterparts in leveraging external knowledge across all sources. In particular, US owned firms were especially adept at exploiting knowledge from most channels, whereas subsidiaries owned by firms from countries other than the EU or US demonstrated an advantage in utilising knowledge from consultants, government and industry associations.

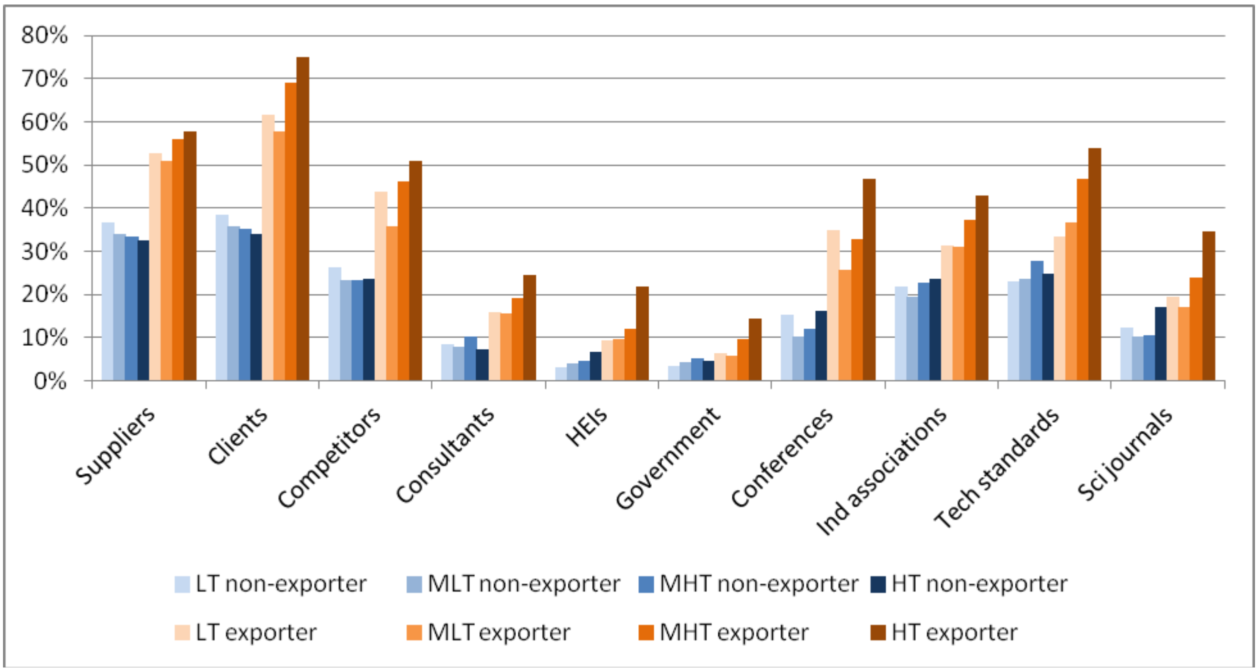
Figure 9 provides evidence that a firm's export orientation was also an important element in understanding how it makes use of sources of knowledge in UK manufacturing. Exporting firms in the high tech industries consistently outperformed not only medium and lower tech exporters in leveraging knowledge but also those high tech firms that were not internationalised. Clients were the most important source of knowledge for exporting firms, followed by suppliers, technical/industry standards and competitors. Overall, the difference between non-exporters and exporters on these scores is a stark one: exporters were often twice as likely to make use of various knowledge sources in innovation; and even exporters in the low tech industries systematically utilised various knowledge sources at a higher rate compared with their non-exporting high tech counterparts. This may in part be explained by some stylised facts of exporters being larger, more productive and paying higher wages (and thus better positioned to acquiring many types of knowledge to gain a competitive edge). More importantly and in the context of innovation activities, the interrelatedness in the decisions to export and to innovate has also been widely documented in the literature, i.e. export-market entry facilitated by product innovation/differentiation, and innovation fostered by the need to gain competitive advantages at the international stage (Lachenmaier 2006; Harris and Li 2009).

Figure 8: Proportion of manufacturing firms utilising knowledge sources by foreign ownership, 2002-2010



Source: weighted UKIS 2005-2011

Figure 9: Proportion of manufacturing firms utilising knowledge sources by technology intensity and exporting status, 2002-2010



Source: weighted UKIS 2005-2011

Notes: LT-Low tech, MLT-Medium-low tech, MHT-Medium-high tech, HT-High tech

Summary of main findings:

- Clients constitute the most important source of knowledge for innovation activities, with suppliers and competitors also being of great importance.
- Alongside market-based sources, a large proportion of firms were also taking advantage of other information sources such as professional and industry associations and technical/industry standards, whereas public institutions (such as government and HEIs) were reported to be least commonly associated with firms' knowledge sourcing for innovation.
- In terms of inter-sectoral differences, manufacturing firms appeared to represent the largest users of knowledge from most sources except consultants, HEIs, government, industry associations and scientific journals or trade publications.
- Suppliers and clients represented main sources of knowledge to around half of manufacturers in Medical etc. Instruments, Electrical Machinery, Chemicals, Rubber and Plastic, Machinery and Equipment, Non-metallic Minerals and lastly Motor and Transport Equipment.
- Outside these frequently utilised market-based channels, manufacturers in Medical etc. Instruments, Electrical Machinery and Chemicals were also the leading users of knowledge from all other sources (e.g. conferences, industry associations, technical/industry standards and scientific journals).
- As might be expected, higher tech manufacturers leveraged knowledge across a wider spectrum of sources at a higher rate than their lower tech counterparts.
- There is evidence that there was a very strong correlation between the size of a manufacturing firm (as measured in employment band) and its orientation of knowledge linkage with external sources.
- The effect of foreign ownership in the UK manufacturing was also evident in that foreign subsidiaries routinely outperformed their indigenous counterparts in leveraging external knowledge across all sources
- Additionally the difference between non-exporters and exporters is also a stark one: exporters were often twice as likely to make use of various knowledge sources in innovation; and even exporters in the low tech industries systematically utilised knowledge sources at a higher rate compared with non-exporting firms in the high tech industries.

7. Cooperation on Innovation Activities in UK Manufacturing Firms

The UKIS questionnaire also compiles information on business cooperation on innovation activities (at both national and international levels), covering the following elements [11]-

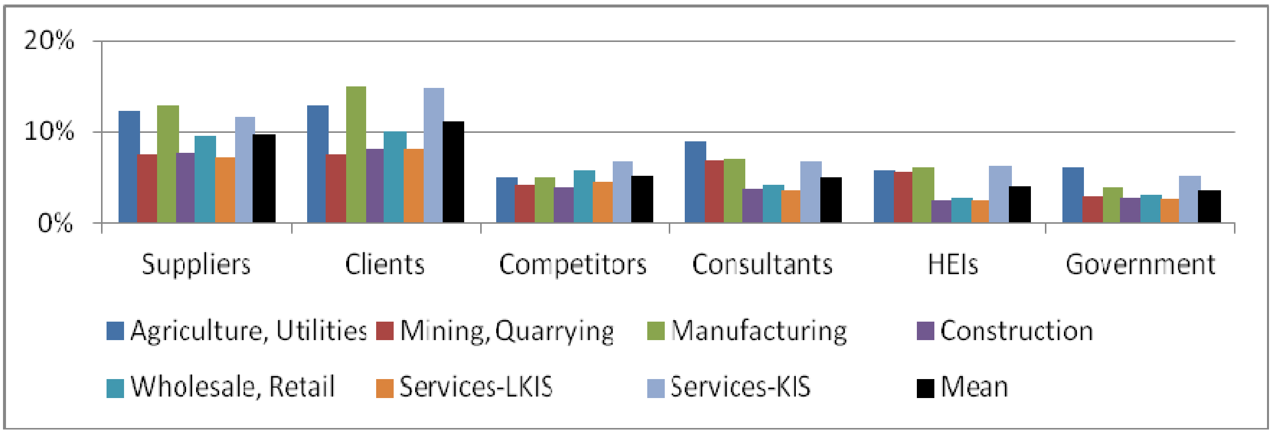
- Market: suppliers of equipment, materials, services or software; clients or customers; competitors or other businesses in the industry; consultants, commercial labs or private R&D industries;

- Institutional: universities or other HEIs; government or public research institutes

7.1 Cooperation in Innovation at the National Level

As illustrated in Figure 10, across the economy, as with the knowledge sourcing behaviour, firms engaged in cooperation for innovation activities in the UK most frequently with market-based partners (namely suppliers and clients but unsurprisingly not competitors), and less so with institutional partners such as HEIs or government. The strength of these partnerships was highest in the Manufacturing, Agriculture and Utilities, and KIS sectors.

Figure 10: Proportion of firms cooperating nationally in innovation, all sectors, 2002-2010



Source: weighted UKIS 2005-2011

Within the manufacturing sector, as Table 4 shows, almost every industry placed great importance on the cooperation with suppliers and clients (notable exceptions are the Clothing and Leather, and Wood Products industries which had relatively low cooperation rates). Across all categories of collaboration (including the public sector), Medical etc, Instruments, Chemicals, Electrical Machinery and Motor and Transport Equipment were most active in building formal partnerships in their innovation activities.

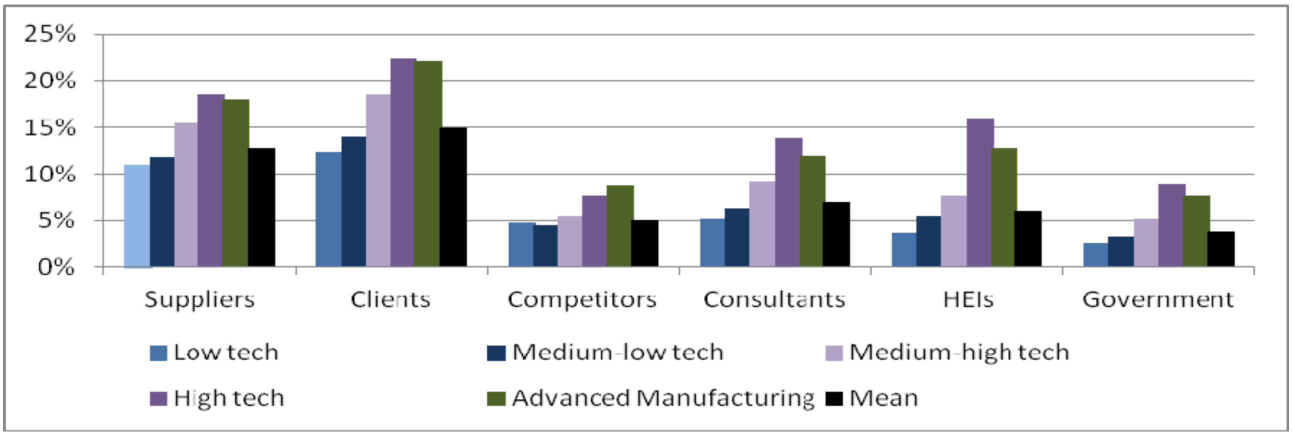
Table 4: Proportion of firms cooperating nationally in innovation and ranking, manufacturing industries, 2002-2010

Industry	Suppliers		Clients		Competitors		Consultants		HEIs		Government	
Medical etc. instruments	20	*1*	26	*1*	9	*1*	15	*1*	18	*1*	9	*1*
Chemicals	17	*2*	23	*2*	7	*3*	13	*2*	14	*2*	6	*2*
Electrical machinery	15	*3*	19	*3*	6	*7*	12	*3*	9	*3*	5	*4*
Motor & Transport eqpt	15	*3*	18	*5*	6	*5*	9	*5*	9	*4*	6	*3*
Machinery, Equip	15	*5*	17	*6*	5	*8*	7	*8*	7	*8*	5	*5*
Rubber, Plastic	15	*6*	18	*4*	5	*9*	9	*6*	8	*6*	4	*8*
Food, Drink	13	*7*	17	*6*	6	*5*	8	*7*	5	*10*	4	*9*
Textiles	12	*8*	14	*9*	7	*4*	6	*9*	6	*9*	4	*7*
Non-metallic minerals	12	*9*	16	*8*	8	*2*	10	*4*	7	*7*	5	*6*
Publishing, Printing	11	*10*	11	*14*	4	*15*	4	*15*	2	*16*	2	*11*
Paper	11	*11*	14	*10*	5	*12*	6	*10*	3	*14*	2	*15*
Furniture	11	*12*	12	*13*	5	*11*	4	*14*	4	*11*	2	*12*
Fabricated metal	11	*13*	12	*12*	4	*14*	5	*13*	4	*12*	3	*10*
Basic metals	10	*14*	14	*11*	3	*16*	6	*11*	8	*5*	2	*13*
Wood products	8	*15*	9	*16*	4	*13*	5	*12*	3	*15*	2	*14*
Clothing, Leather	7	*16*	10	*15*	5	*10*	3	*16*	3	*13*	2	*15*
Mean	13		15		5		7		6		4	

Source: weighted UKIS 2005-2011; figures in italics are rankings

High tech manufacturers cooperated most fully across each type of partner (Figure 11). For example, relative to their low tech counterparts, nearly 4 times high tech firms were cooperating with government, 4 times as many with HEIs and 3 times as many with consultants and around twice as many with competitors or clients. Also compared with average manufactures, advanced manufacturers had an advantage in collaboration with all types of partners and especially with government and HEIs.

Figure 11: Proportion of manufacturing firms cooperating nationally in innovation by technology intensity and advanced manufacturing, 2002-2010

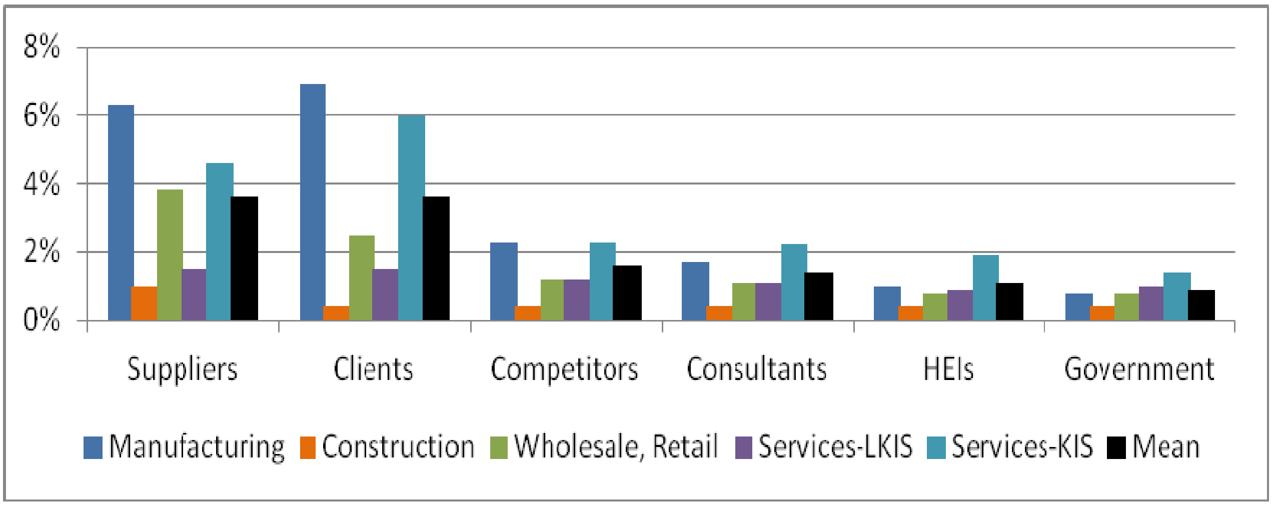


Source: weighted UKIS 2005-2011

7.2 Cooperation in Innovation at the International Level

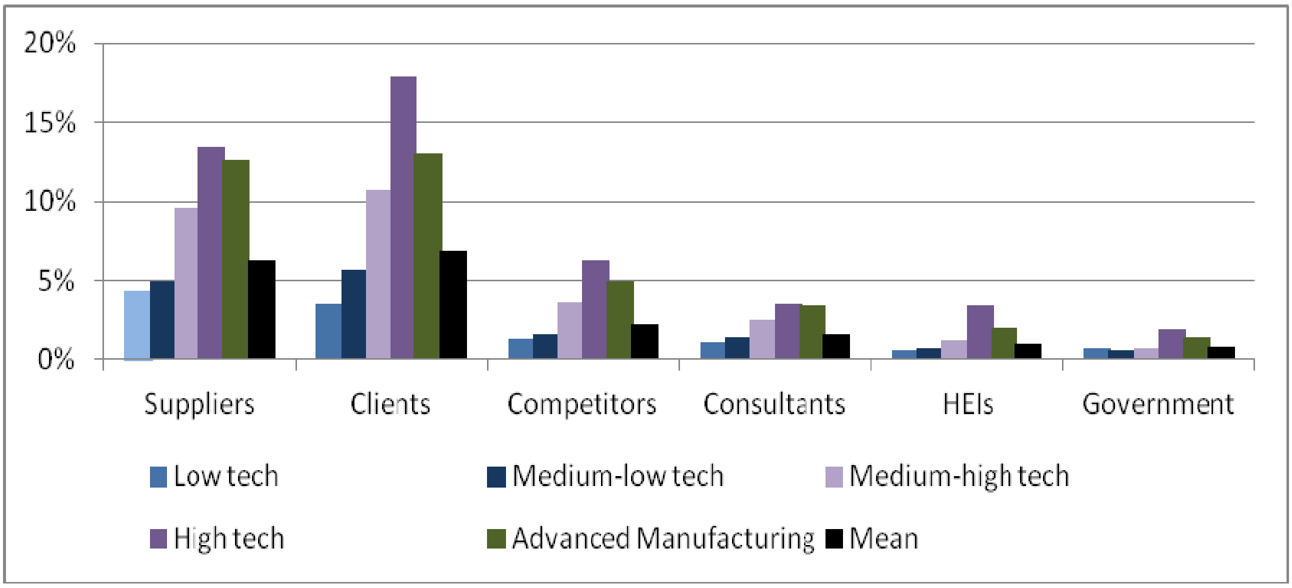
On a global scale, cooperation for innovation was also strongest with suppliers and clients across all sectors, with particularly strong collaboration within the Manufacturing and KIS sectors (Figure 12). Furthermore, KIS firms were especially strong in forming partnerships with government, HEIs and consultants.

Figure 12: Proportion of firms cooperating internationally in innovation, all sectors, 2002-2010



Data source: weighted UKIS 2005-2011
Notes: data for certain sectors (e.g. agriculture, utilities, mining, quarrying) suppressed for disclosure control

Figure 13: Proportion of manufacturing firms cooperating internationally in innovation by technology intensity and advanced manufacturing, 2002-2010



Data source: weighted UKIS 2005-2011

As Figure 13 illustrates, within manufacturing suppliers and clients were by far the most important means of international cooperation across all sectors and many sectors appeared to have especially low values for cooperation with HEIs and government at the global level. Detailed breakdown by manufacturing industries is not available due to small numbers of firms engaging in international cooperation in the UKIS data resulting in statistical disclosure issues. However, at a more aggregated level, industrial classification by technology intensity shows a fairly linear pattern: low tech and medium-low tech firms had lower levels of international cooperation than medium-tech or (especially) high tech manufacturers. Advanced manufacturers were around twice as likely to cooperate internationally with all partners relative to average manufactures.

Summary of main findings:

- Firms engaged in cooperation for innovation activities in the UK most frequently with market-based partners (namely suppliers and clients), and less so with institutional partners such as HEIs or government. The strength of these partnerships was highest in the Manufacturing, Agriculture and Utilities, and KIS sectors.
- Within the manufacturing sector, Medical etc. Instruments, Chemicals, Electrical Machinery and Motor and Transport Equipment were most active in building formal partnerships in their innovation activities at the national level.

- Within the UK, high tech manufacturers cooperated most fully across each type of partner. And compared with average manufactures, advanced manufacturers had an advantage in collaboration with all types of partners and especially with government and HEIs.
- In terms of international cooperation in innovation activities, such collaborative partnership was also strongest with suppliers and clients across all sectors, with particularly strong collaboration within the Manufacturing and KIS sectors.
- Furthermore, KIS firms were especially noticeable in forming partnerships with overseas government, HEIs and consultants.
- Within the manufacturing sector, suppliers and clients were by far the most important means of international collaboration. Low tech and medium-low tech manufactures had lower levels of international cooperation than medium-tech or (especially) high tech manufacturers. Advanced manufacturers also had a notable advantage in cooperation with international partners.

8. Absorptive Capacity in UK Manufacturing Firms

Following the approach developed in Harris and Li (2009), we constructed an empirical multi-index of absorptive capacity to measure a firm's ability to internalise and appropriate external knowledge for innovation activities. Despite the lack of direct information on the concept of absorptive capacity, the UKIS compiles information outlining an extensive picture of a firm's behaviour in 'external' knowledge-sourcing, collaborative partnership and 'internal' implementation of business strategies and practices, which can be expected to relate to the level of absorptive capacity.

Here the first sets of variables that were employed to create the absorptive capacity measure consist of those used to study external knowledge sources and national/international innovative activities as discussed in Sections 6 and 7 earlier. Additionally, we also included measures for firms' ability to implement changes in cooperate strategy and practices covering the following areas:

- new or significantly changed corporate strategies;
- new management techniques within firms (e.g. just-in-time, 6 Sigma, Investors in People);
- major changes to organisational structures (e.g. introduction of cross-functional teams, outsourcing of major business functions);
- changes to marketing concepts or strategies

These 26 elements[12] of knowledge-sourcing, cooperation and corporate strategies exhibit a high degree of internal statistical consistency with a Cronbach's Alpha score of 0.89 (scale reliability coefficient). In order to reduce the number of variables under investigation and exact crucial information on the firm's capability of absorbing information and appropriating knowledge, we undertook a factor analysis (in conjunction with weighting and oblique oblimin rotation) using these 26 input variables outlined above.

Five principal components have been retained with eigenvalues above one, accounting for 58% of the total variance in the data. This procedure yielded 5 factors capturing 5 distinct aspects of a firm's absorptive capacity. Table 5 illustrates the structure of the factor loadings associated with each factor and input variable[13]. Each factor was interpreted to principally capture the variables for which it had the highest factor loadings, representing the firm's absorptive capacity for general external knowledge (Factor 1), national cooperation (Factor 2), international cooperation (Factor 3), implementation of new business strategy and practice (Factor 4) and lastly, more specialist knowledge from HEIs, government or public research institutes, consultants and commercial labs (Factor 5). These 5 indices were then normalised to distribute between zero and one.

Table 5: Structure matrix of factor loadings: correlations between variables and rotated common factors

Input Variables	**Factor 1** General external knowledge	**Factor 2** National co-operation	**Factor 3** International co-operation	**Factor 4** Business strategy and practice	**Factor 5** Specialist knowledge from HEIs/government	**Kaiser-Meyer-Olkin Measures**†
Sources of knowledge/info for innovation						
Suppliers/materials/services	*0.748*	0.047	-0.019	0.068	-0.118	0.926
Clients/customers	*0.764*	0.064	0.015	0.118	-0.146	0.891
Competitors	*0.732*	0.037	0.020	0.072	-0.088	0.917
Consultants/commercial labs	0.306	0.088	0.022	0.109	*0.420*	0.918
Universities/other HEIs	0.110	0.064	0.042	0.078	*0.731*	0.802
Government/public research institutes	0.184	0.078	-0.007	0.049	*0.685*	0.843
Conferences/trade fairs/exhibitions	*0.625*	-0.023	0.039	0.015	0.129	0.945
Professional & industry associations	*0.767*	-0.012	-0.013	-0.046	0.116	0.886
Technical/industry standards	*0.758*	0.012	-0.007	-0.009	0.083	0.894
Scientific journals & trade publications	*0.630*	-0.052	0.024	-0.067	0.275	0.933
Co-operation partners on innovation activities (National)						
Suppliers/materials/services	0.143	*0.730*	0.001	0.044	-0.193	0.899
Clients/customers	0.151	*0.726*	0.030	0.070	-0.189	0.892
Competitors	0.065	*0.764*	-0.013	-0.035	-0.088	0.908
Consultants/commercial labs	-0.042	*0.747*	0.031	0.028	0.116	0.905
Universities/other HEIs	-0.132	*0.675*	0.069	0.030	0.340	0.843
Government/public research institutes	-0.104	*0.743*	0.012	-0.019	0.262	0.858

Notes: weighted UKIS 2005-2011; factors extracted using principal-component method in conjunction with weighting, rotated using oblique oblimin technique

Table 6 (continued): Structure matrix of factor loadings: correlations between variables and rotated common factors

Input Variables	Factor 1 General external knowledge	Factor 2 National co-operation	Factor 3 International co-operation	Factor 4 Business strategy and practice	Factor 5 Specialist knowledge from HEIs/government	Kaiser-Meyer-Olkin Measures†
Co-operation partners on innovation activities (International)						
Suppliers/materials/services	0.099	0.139	*0.588*	0.024	-0.138	0.905
Clients/customers	0.058	0.158	*0.595*	0.060	-0.080	0.897
Competitors	0.006	0.034	*0.742*	-0.006	-0.033	0.899
Consultants/commercial labs	-0.008	-0.058	*0.819*	-0.011	0.024	0.892
Universities/other HEIs	-0.065	-0.085	*0.834*	-0.012	0.106	0.815
Government/public research institutes	-0.049	-0.108	*0.844*	-0.028	0.065	0.809
Innovation in business strategy and practices						
Corporate strategies/practices	-0.033	-0.016	0.006	*0.806*	0.002	0.890
Management techniques	-0.051	-0.005	-0.008	*0.726*	0.052	0.924
Organisational structure	0.001	-0.031	0.001	*0.779*	0.026	0.902
Marketing strategies	0.071	0.007	-0.002	*0.707*	-0.024	0.925
No. of observations						54,709
LR test: independent vs. saturated $\chi^2(325)$						5.8e+05
Overall KMO						0.889

Notes: weighted UKIS 2005-2011; factors extracted using principal-component method in conjunction with weighting, rotated using oblique oblimin technique

8.1 Absorptive Capacity – Sectoral Disparity

Average scores across sectors of each absorptive capacity index are presented in Table A6 in the Annex. Overall manufacturing firms appeared to have the highest absorptive capacity for general external knowledge (the first principal component) and also a noticeable advantage in its absorptive capacity for national and international cooperation, and business strategy and practice. Another sector that stood out is the Knowledge-Intensive Services (KIS) which dominated in its absorptive capacity for business strategy and practice, national and international cooperation and was only second to manufacturing in its principal absorptive capacity for general external knowledge. Sectors such as construction, Less Knowledge-Intensive Services (LKIS) and wholesale and retail performed fairly poorly in terms of overall ranking in this table.

To control for the influence of outliers (which can sometimes drive means values as presented in Table A6) and provide a more comprehensive account of sectoral heterogeneity at all levels of absorptive capacity, Figure 14 plots the empirical cumulative distribution functions (ECDFs) of 5 absorptive capacity indices for all sectors. The cumulative distribution function (CDF) denotes, at each possible score of absorptive capacity index (i.e. x on the horizontal axis), the probability of receiving that score or a lower one (i.e. $P(x)$ on the vertical axis). Hence $P(x)$ is the non-decreasing probability of the absorptive capacity score less than a given score x ; $P(x)$ goes to zero as x decreases $\lim_{x \to -\infty} P(x) = 0$ and conversely, it goes to unity as x reaches its maximum score $\lim_{x \to \infty} P(x) = 1$. Here we employ the empirical cumulative distribution function (ECDF) of absorptive capacity as a non-parametric estimator of the distribution function based on our empirical data. The absorptive capacity scores are normalised and bounded between 0 and 1 (x-axis), and by definition, the ECDF $P(x)$ contains probability/proportion values ranging from 0 to 1 (y-axis). For a given set of scores of absorptive capacity, the value of the ECDF $P(x)$ at an absorptive capacity score x is the proportion of scores in the set that are no greater than x .

A common application of ECDFs is to determine the differences in distributions of sub-groups or a relation of stochastic dominance (for instance the income inequality between different population subgroups, or productivity gaps amongst firms of differing characteristics). For example, let us consider the distributions of absorptive capacity of sectors A and B, represented by $P_A(x)$ and $P_B(x)$ respectively. Then distribution A stochastically dominates distribution B if the plotted ECDF of distribution A lies to the right of the distribution B, i.e. for any score of , $P_A(x) \leq P_B(x)$. More specifically, if x denotes a given score of absorptive capacity, then the inequality in the two distributions (of sectors A and B) indicates that the proportion of firms in sector A with absorptive capacity scores no greater than x is no greater than the proportion of such firms in B. In other words, whatever absorptive capacity levels we consider, there is always a larger proportion of firms with higher scores of absorptive capacity in sector A than in sector B, and therefore A is the dominating and B the dominated distribution.

As shown in Figure 14, there seems to be considerable variation in the empirical distributions of absorptive capacity indices across all sector groups, except at extremely low or high scores of absorptive capacity where the inter-sectoral differences become indistinguishable. Thus it is worth noting that the relationships of stochastic dominance referred to here are mostly *restricted* (and sometime weak) dominance, as the inequality holds over some restricted range of the argument x rather than for all possible values (as is often the case in empirical distributions). Overall the patterns revealed by these graphs are broadly similar to those based on the mean statistics in Table A6.

In the case of absorptive capacity for general external knowledge, the distribution of Manufacturing dominated those of other sectors mostly throughout all values of the index (i.e. its empirical distribution lies to the right of other sectors). The Knowledge-Intensive Services (KIS) also had a leading position and was only dominated by Manufacturing. Notably the Less Knowledge-Intensive Services (LKIS) sector appeared to have the lowest capacity with its distribution statistically dominated by all other sectors nearly at all levels.

The distributions of the absorptive capacity for national and especially international cooperation appeared to be most skewed (especially given the small fraction of firms engaging in the latter cooperation activities), with the top quartile (75% percentile) scores of 0.15 and 0.01 for national and international cooperation respectively. In terms of the absorptive capacity for national cooperation, Manufacturing, KIS and Agriculture and Utilities seemed the strongest performers with the LKIS and Construction sectors being mostly dominated at medium-range of the index but such differences remained largely insignificant at other levels of the index. As to the absorptive capacity for international cooperation, Manufacturing was seen to weakly dominate other sectors at a rather small range of the index and thus there was little evidence of sectoral heterogeneity in this respect.

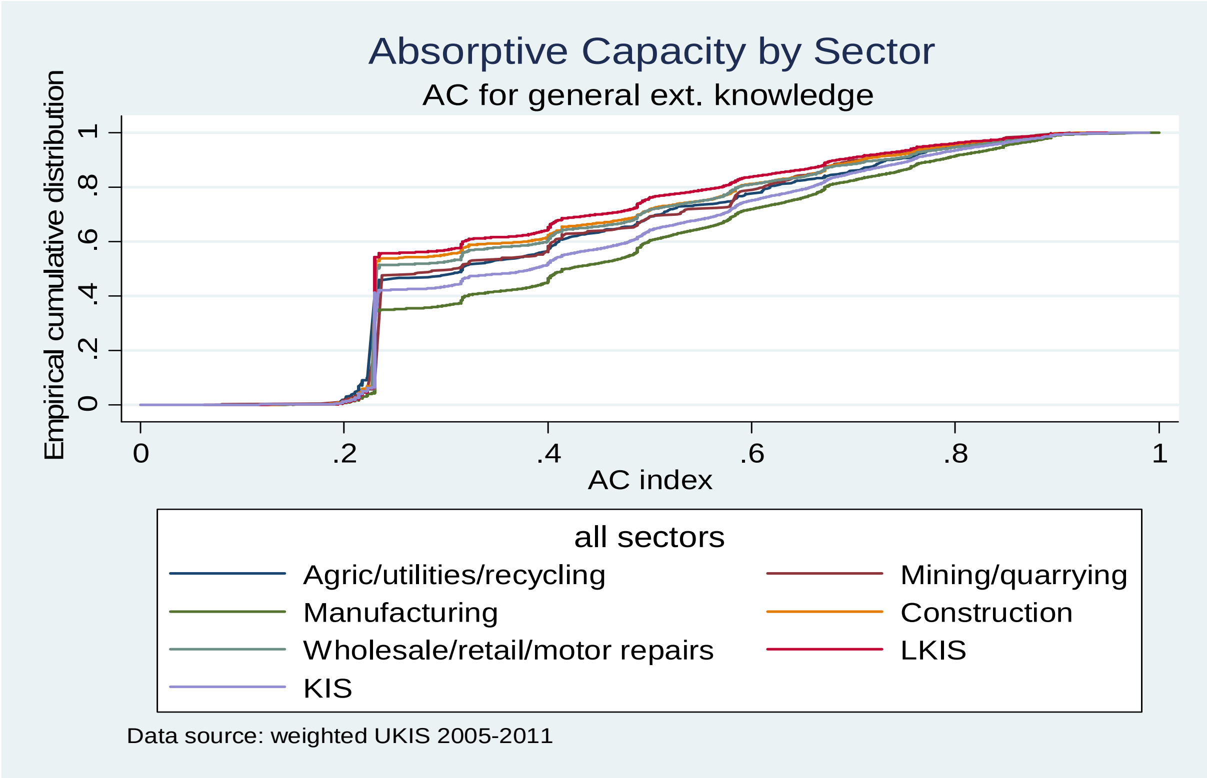
Considering next the absorptive capacity for business strategy and practice, as might be expected KIS sector had stochastic dominance over all other sectors (i.e. weak dominance over Manufacturing and Agriculture and Utilities but strong dominance over Mining and Quarrying, LKIS, Construction and Wholesale, Retail and Motor Repairs) across the absorptive capacity index. Meanwhile, Manufacturing and Agriculture and Utilities sectors also performed strongly although the differences start to dissipate at the top end of the absorptive capacity index.

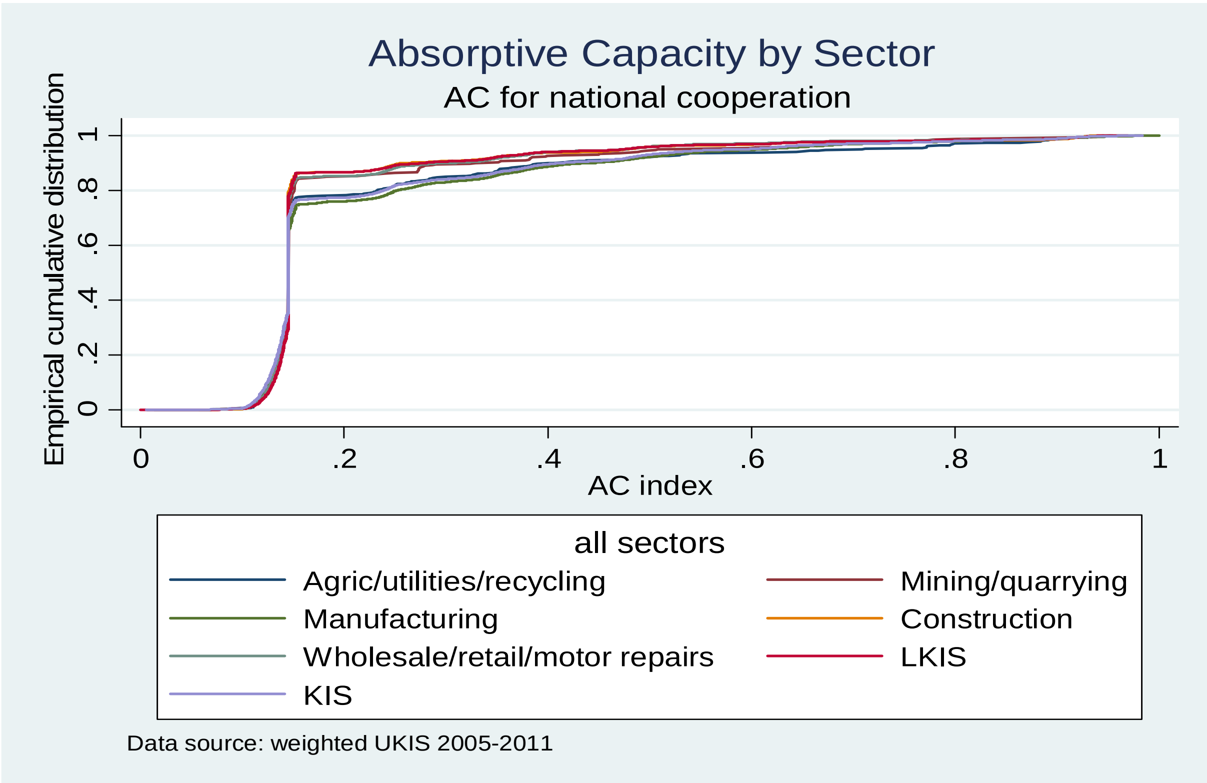
Lastly, the absorptive capacity index for specialist knowledge seemed to be distributed more similarly regardless of the sector firms originated in. The distribution of Manufacturing was weakly dominated by others at low levels of absorptive capacity and the distributions of sectors such as Agriculture and Utilities, Mining and Quarrying and KIS showed some weak dominance at higher levels of absorptive capacity, although most of this inequality remained indiscernible.

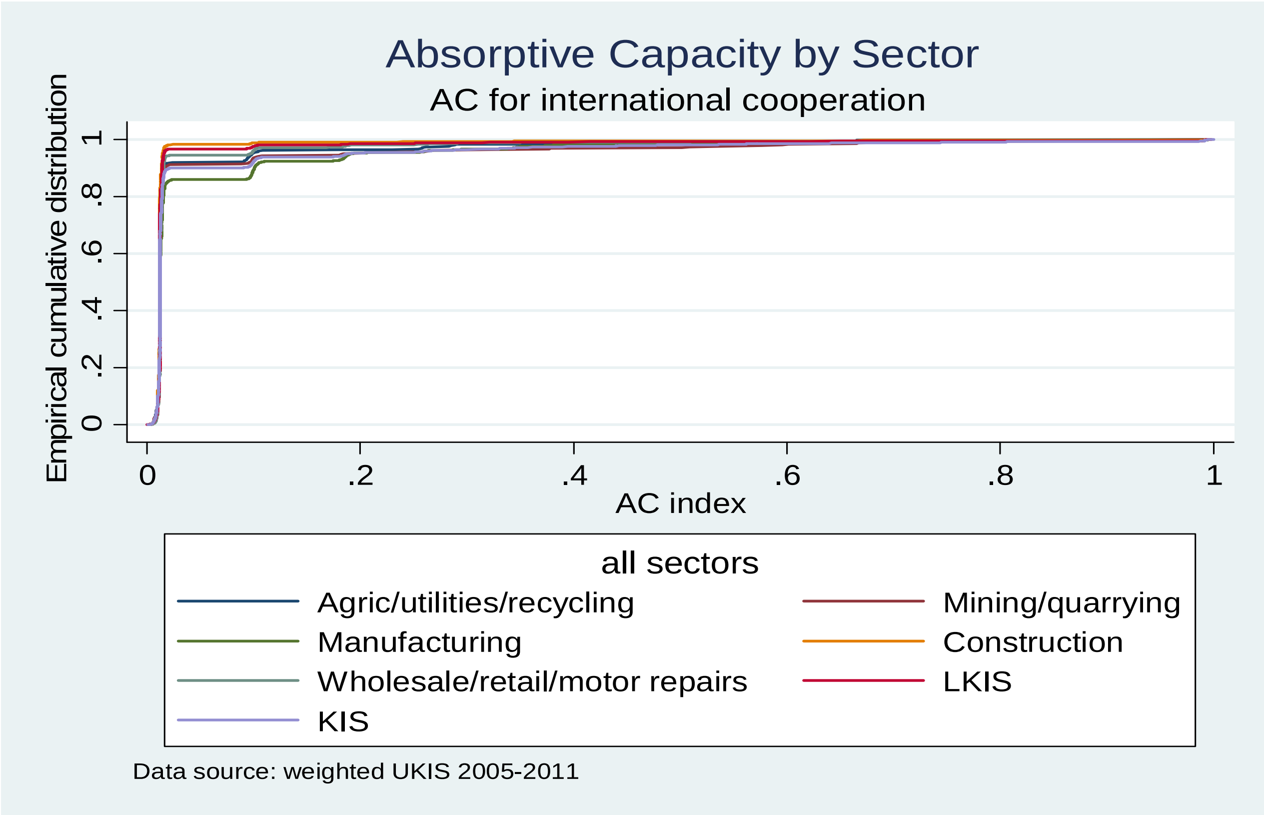
What's more, the distributions of absorptive capacity indices for industries (by technology intensity) within manufacturing are reported in Figure A1 in the Annex. Overall, there appears to be substantial inequality amongst different types of manufacturers in their scores of absorptive capacity although (as with the case presented in Figure 14) such variations are usually indistinguishable at extremely low values of absorptive capacity and the distributions tend to converge at extremely high levels.

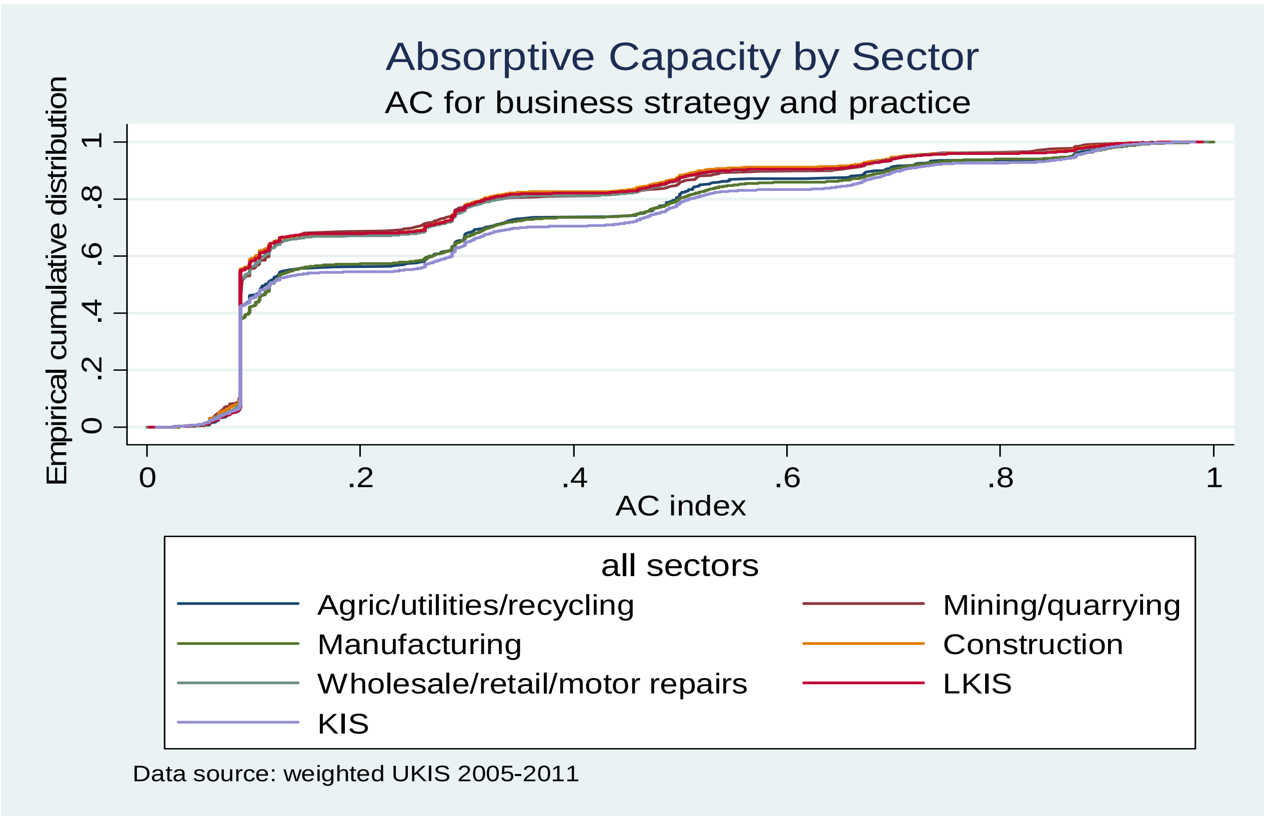
As these diagrams in Figure A1 illustrate, the distribution of high tech manufactures clearly dominated other types of manufacturers in all five aspects of absorptive capacity, i.e. the distribution of the high tech industries nearly always lie to the right of other distributions. Although being dominated by the distribution of high tech manufacturing, the distribution of medium-high tech manufacturing firms also had a strong stochastic dominance over those of medium-low and low tech firms. Perhaps more surprisingly, the distribution of the medium-low tech firms seemed to be dominated by that of their low tech counterparts in the absorptive capacity for general external knowledge (except at very low or high levels), which again indicates the boundaries as per the OECD's classification within these two groupings may overlap.

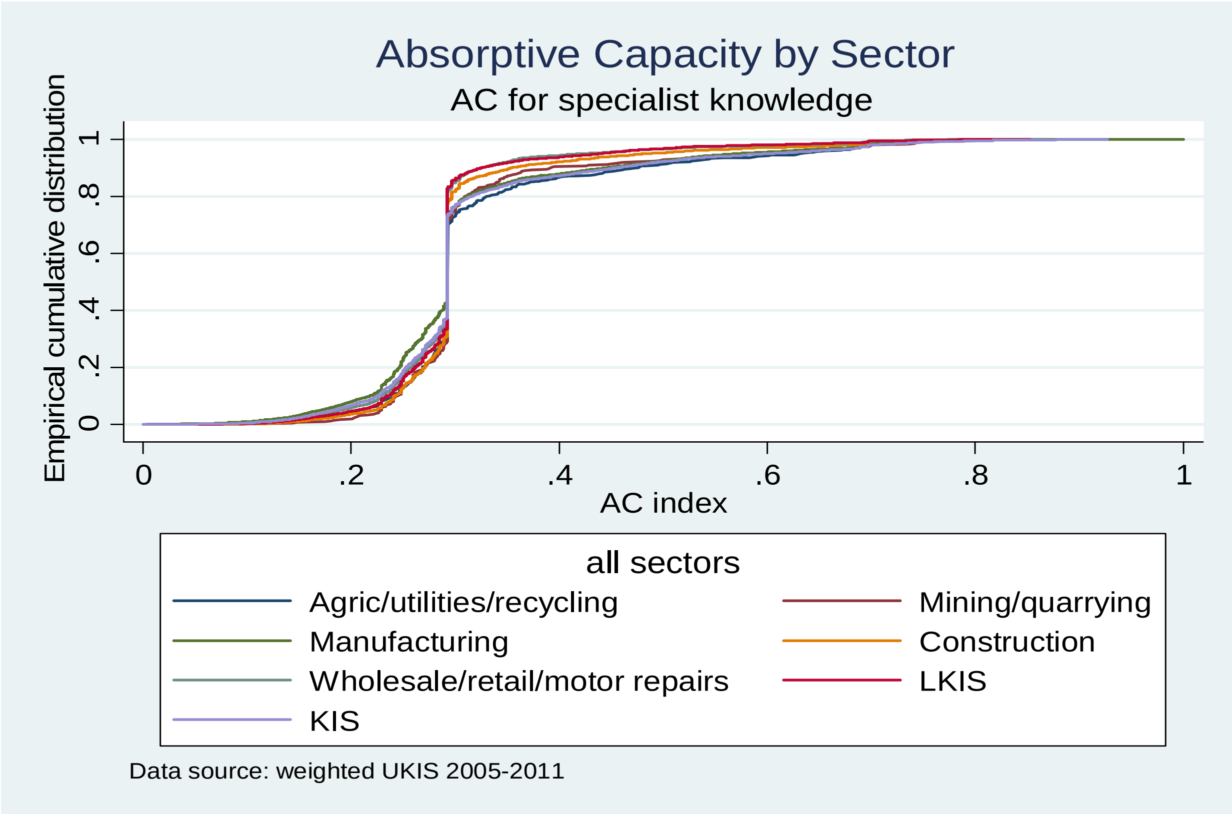
Figure 14: Empirical cumulative distribution of absorptive capacity indices, all sectors, 2002-2010






Absorptive Capacity by Sector
AC for international cooperation
Empirical cumulative distribution
0
.2
.4
.6
.8
1
AC index
all sectors
Agric/utilities/recycling
Manufacturing
Wholesale/retail/motor repairs
KIS
Mining/quarrying
Construction
LKIS
Data source: weighted UKIS 2005-2011


Absorptive Capacity by Sector
AC for business strategy and practice
Empirical cumulative distribution
0
.2
.4
.6
.8
1
AC index
all sectors
Agric/utilities/recycling
Manufacturing
Wholesale/retail/motor repairs
KIS
Mining/quarrying
Construction
LKIS
Data source: weighted UKIS 2005-2011



8.2 The Spatial Distribution of Absorptive Capacity in UK Manufacturing

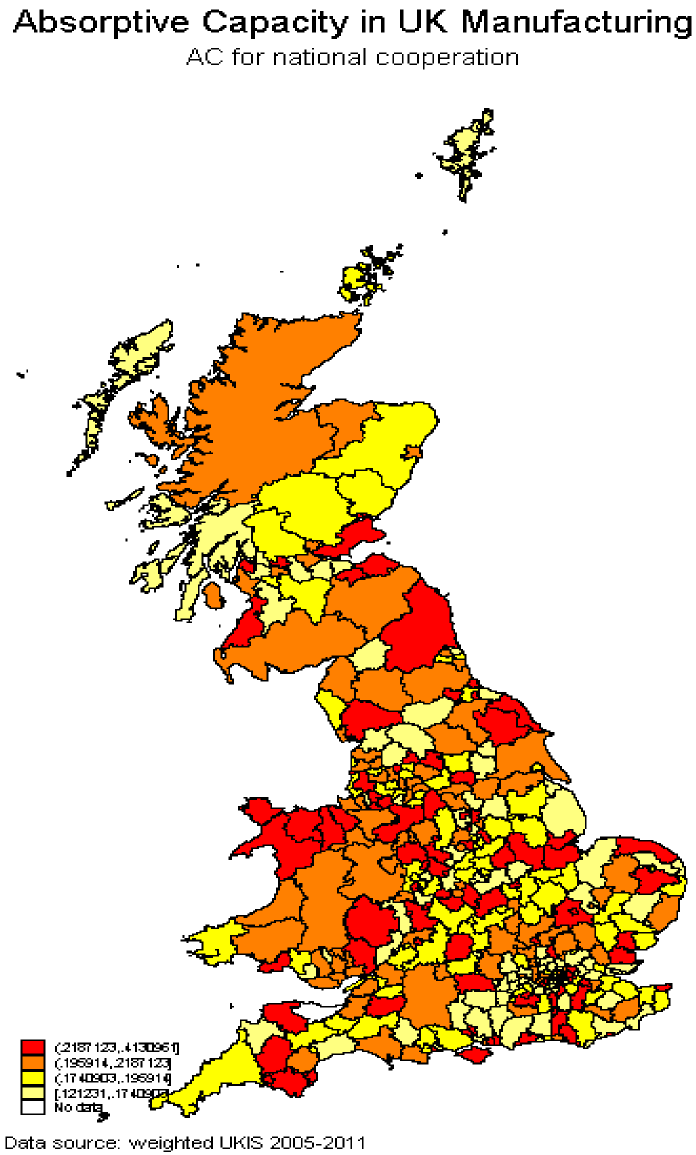
A number of 'heat maps' showing performance of absorptive capacity for UK local authorities are provided in Figure 15 and at a more aggregated level the mean scores of each index are also reported in Table A7 in the Annex for each GO region.

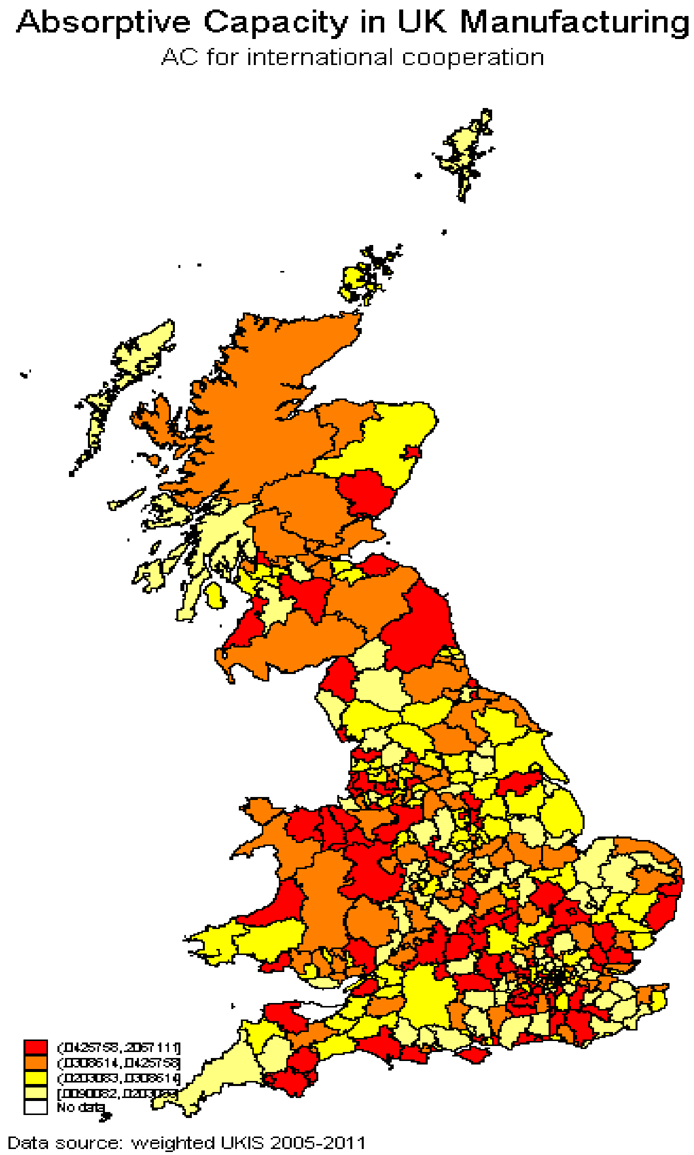
In terms of the absorptive capacity for general external knowledge, Wales and Scotland appeared to be associated with higher levels overall - it seems that the areas with strong manufacturing component tended to have higher capacity. The essentially 'clustered' nature of absorptive capacity was revealed, especially in the North East and East of England. A surprise was the low rank of London and also the West Midlands, suggesting that the nature of absorptive capacity in these regions may be more 'industry specific' (e.g. dominance towards services away from manufacturing in London may be an important factor). Our findings here echo those highlighted in a recent study of spatial spillovers and 'place' effects in the UK by Harris and Moffat (2012c); that is productivity spillovers are distributed across the country and not just confined to the Capital or other major cities. Finally, these results should also be considered bearing in mind that there are differences in the underlying industrial structure of UK regions.

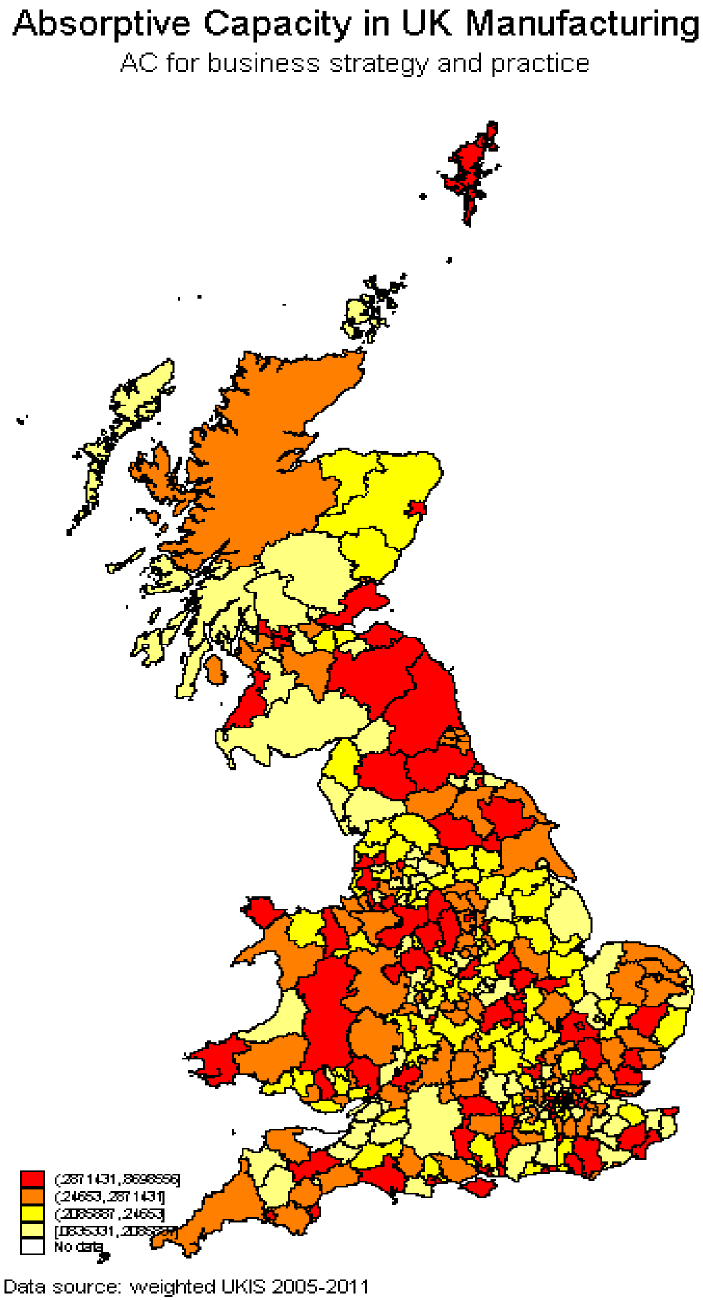
The picture of absorptive capacity for national cooperation is more ‘bitty’ than that for other types of absorptive capacity. The areas with higher level of capacity were seen around the UK periphery (Scotland, Wales and parts of Northern England) but there were also stronger areas embedded within the Midlands, South East and South West. As to the capacity for cooperation at the international level, the strongest areas were similar to those found at the national level - there were clusters of relative strength in Wales and Scotland, the North East and a band in the Midlands.

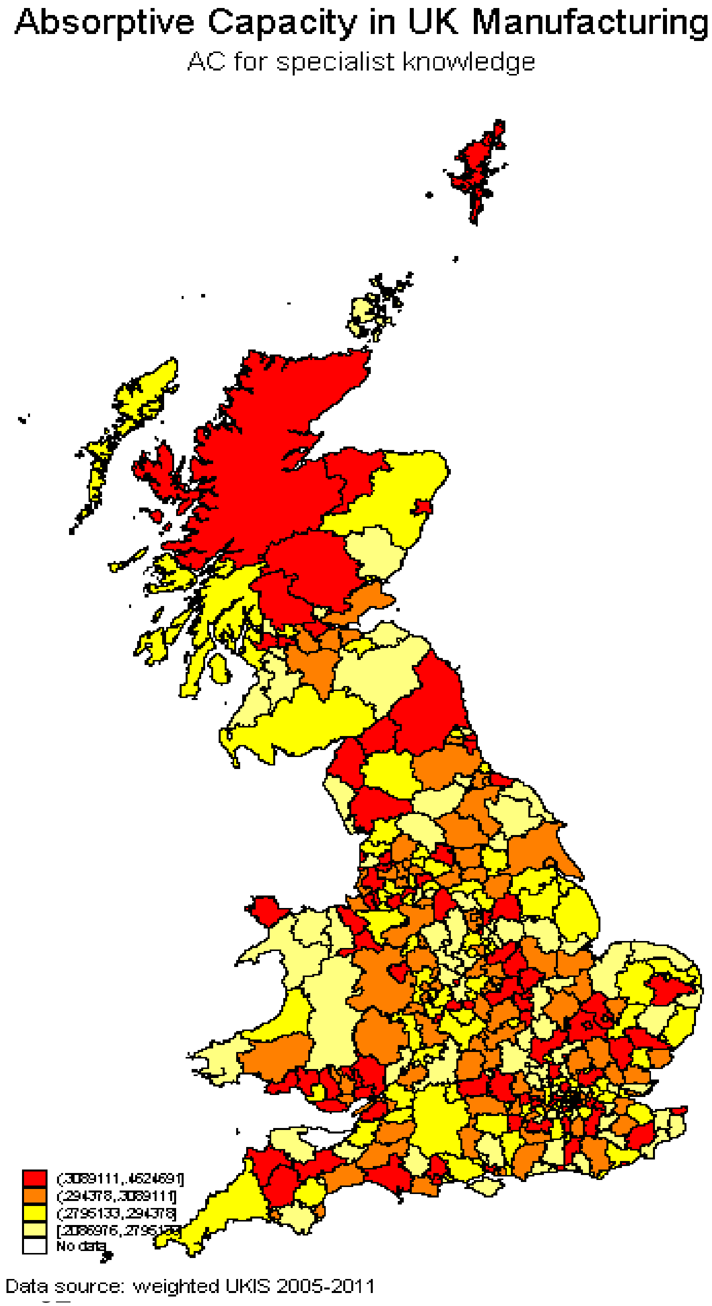
Given the ‘hub’ effect of London and the South East (hosting leading global businesses), these regions performed more strongly on their absorptive capacity for business strategies and practices, which may be a result of the greater number of head office functions which occurred in these regions. What’s more, there is a strong association between being in the more heavily urbanised areas of the country and a strong performance against this variable. Lastly, in terms of the regional absorptive capacity for specialist knowledge from HEIs and government, Scotland was a strong performer visually against this variable, as were the North East and North West and the South of Wales. Again in the rest of the UK there were identifiable clusters (the Midlands, Home Counties) but there was no overall consistent pattern which can be defined across each and every region.

Figure 15: Spatial distribution of absorptive capacity indices in UK manufacturing firms, 2002-2010






Absorptive Capacity in UK Manufacturing
AC for business strategy and practice
(.2871431,.8696556]
(.24653,.2871431]
(.2085887,.24653]
[.0835331,.2085887]
No data
Data source: weighted UKIS 2005-2011


Absorptive Capacity in UK Manufacturing
AC for specialist knowledge
(.3089111,.4624691]
(.294378,.3089111]
(.2795133,.294378]
[.2086976,.2795133]
No data
Data source: weighted UKIS 2005-2011

Summary of main findings:

- Following the approach developed in Harris and Li (2009), we constructed an empirical multi-index of absorptive capacity to measure a firm's ability to internalise and appropriate external knowledge for innovation activities.
- Our empirical indices of absorptive capacity consist of the following 5 elements - the absorptive capacity for general external knowledge (Factor 1), for national cooperation (Factor 2), for international cooperation (Factor 3), for implementation of new business strategy and practice (Factor 4) and lastly, for more specialist knowledge from HEIs, government or public research institutes, consultants and commercial labs (Factor 5).
- Based on the average scores of absorptive capacity indices, manufacturing firms appeared to have the highest absorptive capacity for general external knowledge and also a noticeable advantage in its absorptive capacity for national and international cooperation, and business strategy and practice.
- Our analyses of the empirical cumulative distribution functions (ECDFs) of 5 absorptive capacity indices shed further light on the relation of stochastic dominance between different sectors.
- In the case of absorptive capacity for general external knowledge, the distribution of Manufacturing dominated those of other sectors mostly throughout all values of the index. KIS sector also had a leading position and was only dominated by the Manufacturing.
- In terms of the absorptive capacity for national cooperation, Manufacturing, KIS and Agriculture and Utilities seemed the strongest performers; as to the absorptive capacity for international cooperation, there was little evidence of sectoral heterogeneity.
- In the case of the absorptive capacity for business strategy and practice, KIS sector had stochastic dominance over all other sectors.
- The absorptive capacity index for specialist knowledge seemed to be distributed more similarly regardless of the sector firms originated in.
- Within the manufacturing sector, there appears to be substantial inequality amongst different types of manufacturers: the distribution of high tech manufactures clearly dominated other types of manufacturers in all five aspects of absorptive capacity; and the distribution of medium-high tech manufacturing firms also had a strong stochastic dominance over those of medium-low and low tech firms.

- Major spatial variations in the regional absorptive capacity have been documented in a number of 'heat maps'. In terms of the absorptive capacity for general external knowledge, Wales and Scotland appeared to be associated with higher levels overall - it seems that the areas with strong manufacturing component tended to have higher capacity.
- The essentially 'clustered' nature of absorptive capacity was revealed, especially in the North East and East of England.
- The picture of absorptive capacity for national and/or international cooperation is more 'bitty': the areas with higher level of capacity were seen around the UK periphery (Scotland, Wales, and parts of Northern England) and a band in the Midlands.
- Given the 'hub' effect of London and the South East (hosting leading global businesses), these regions performed more strongly on their absorptive capacity for business strategies and practices.
- Lastly, in terms of the regional absorptive capacity for specialist knowledge from HEIs and government, Scotland was a strong performer as were the North East, North West and the South of Wales.

9. The Nexus between Knowledge Sources, Innovation Input and Output

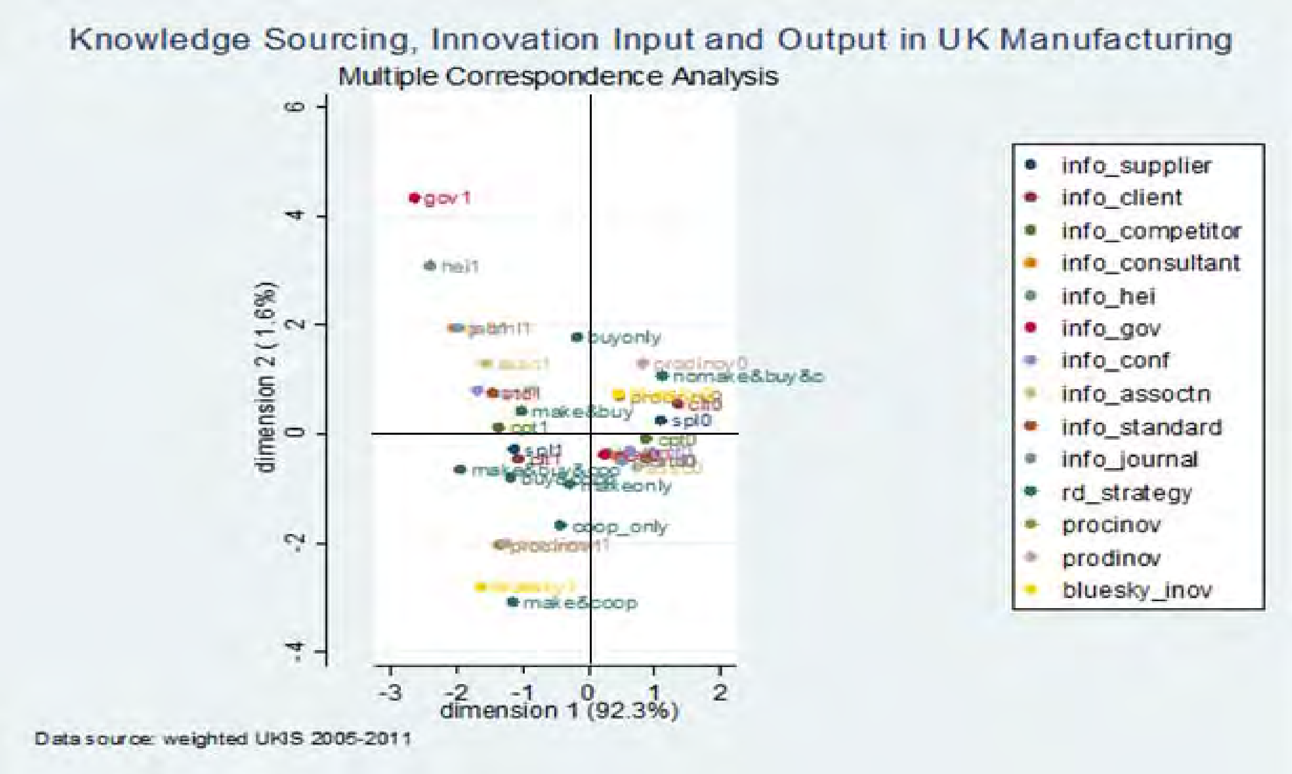
It is beyond the scope of this report to formally investigate the relationship between innovation input and output in the value chain in a multivariate framework of econometric modelling. Therefore, this section provides some initial descriptive analysis to shed light on the pathway of innovation in UK manufacturing. We consider the nexus between knowledge sources, cooperation partners used in innovation activities, formal R&D strategies, innovation output, and lastly IP protection strategies. In particular, in terms of R&D strategy, we measure three forms of R&D spending, viz. intramural R&D ('make'), extramural R&D ('buy') and collaborative R&D ('cooperate'), a combination of which yields seven R&D strategies – 1) make only, 2) buy only, 3) cooperate only, 4) make and buy, make and cooperate, 5) buy and cooperate, 6) make, buy and cooperate, and lastly 7) none of the above (i.e. no R&D). With respect to the innovation output, we measure process and/or product innovation, as well as a more radically form of blue sky innovation, i.e. product new to the market/industry. Finally, as to the strategies for capturing value of innovation, we focus on patent or any industrial design registered.

A multiple correspondence analysis (MCA) was employed to study the associations between aforementioned innovation-related variables with the results plotted in a geometric (or Euclidean) space in Figures 16 and 17. As a special case of principal components analysis and an extension of the simple correspondence analysis, the MCA method provides a multivariate descriptive technique for understanding patterns of relationship between a number of variables by combining them into visual ‘maps’ and presenting the interrelatedness by clustering of variables. It is worth noting that although interpretation of association is based on proximities between points in the ‘maps’, the magnitude of distance between points in geometric space usually does not have a straightforward interpretation.

The MCA diagram plots individual values of each variable on a two-dimensional ‘map’: in the case of a binary variable this is split into two points suffixed with numbers 0 and 1 (e.g. in Figure 16, ‘gov1’ denotes ‘government used as knowledge source’ and ‘gov0’ denotes otherwise); and in the case of an ordinal variable this is split into various categories consisting of its numeric scores (e.g. in Figure 16, ‘rd_strategy’ is split into 7 categories as discussed above, such as ‘makeonly’, ‘buyonly’, ‘make&buy’, ‘make&buy&coop’).

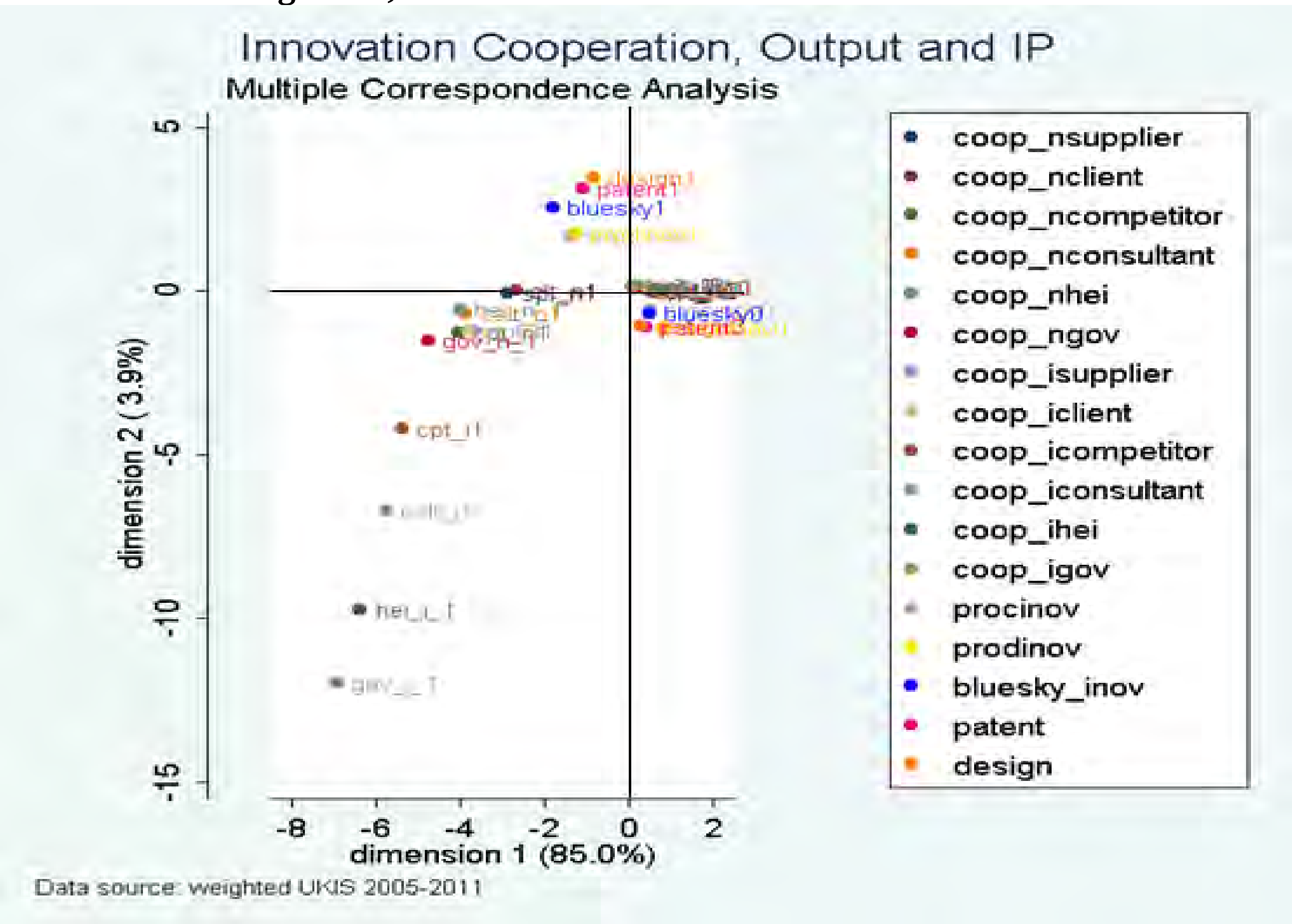
Figure 16 illustrates the results of a MCA of knowledge sources, R&D strategies and innovation output, plotting 20 variables/points in a geometric space (two dimensions represented on the horizontal and vertical axes respectively). Here the two dimensions retained jointly explain nearly 94% of total inertia in the data and thus have considerable explanatory power.

Figure 16: The nexus between sources of knowledge, R&D strategies and innovation output in UK manufacturing firms, 2002-2010



Categories that are associated are placed close together in the 'map'. Given that the first dimension explains over 92% of inertia (compared with under 2% as explained by the second dimension) the horizontal axis is obviously the most important dimension and able to differentiate most clearly along the categories of variables under consideration; in other words, horizontal proximity presents far stronger association vis-à-vis vertical proximity on the 'map'. More specifically, in Figure 16, the bottom-left quadrant suggests that product innovators were also likely to be process innovators (and vice versa), and the more radical innovators (with blue sky innovations) turned to combine 'make'/intramural and 'cooperation' in their R&D investment. Relating knowledge sources to R&D strategies, the clustering of categories near origin seems to suggest that UK manufacturers tended to use a number of market-based knowledge sources at the same time such as suppliers, clients, competitors, technical standards, industry associations, which is also associated with combining various forms of R&D strategies such as 'make' only, 'make' and 'buy', 'buy' and 'cooperate', and 'make', 'buy' and 'cooperate'. Interestingly, the firms that used public institutions such as HEIs and government as their knowledge sources (top left corner) seemed to have more distinct patterns of innovation behaviour and less related to other categories. Also notably in the top-right quadrant, categories for no utilisation of various knowledge sources tended to cluster with those for no R&D expenditure and/or for no innovation output (which also indicates the agreement in measuring scales in the underlying data), which is intuitively appealing.

Figure 17: The nexus between cooperation, innovation output and protection in UK manufacturing firms, 2002-2010



Finally, linking patterns in the UK manufacturers' cooperation partners (both national, prefixed with 'coop_n' and international prefixed with 'coop_i') to their innovation output (e.g. process/product/blue sky innovation) and value capturing of such output (e.g. patent, registered design), Figure 17 shows the nexus between these relevant categories. Again the two extracted dimensions explain as high as 89% of total inertia in the data and the principal dimension (1) alone explains 85% of inertia and thus is the most important dimension to observe. The top-left quadrant suggests a clear and close association between blue sky innovation and exploiting value from such path-breaking innovation by registering patents and industrial designs. Again similar to Figure 16, there is often not a clear-cut distinction between being a product and a process innovator (i.e. investment in one type of innovation is associated with that in another type).

Notably, the bottom-left quadrant shows a major clustering of cooperation in innovation activities with all 6 types of domestic partners (namely suppliers, clients, competitors, consultants, HEIs and government); that is, the firms engaged in cooperation with one national partner were also likely to report cooperation with other types of partners at national level. At the same time, those firms that participated in cooperation with overseas partners in one form were also more likely to engage in international cooperation in another form (more specifically, there was a noticeable clustering in the international cooperation with HEIs, government, consultants and competitors). Again as with Figure 16, the clustering of variables around the origin in the right quadrant shows that firms that did not engage in cooperation activities were more likely to also report that they were not active in innovation and hence protection of innovation output.

Summary of main findings:

- Product innovators were also likely to be process innovators (and vice versa), and the more radical innovators (with blue sky innovations) turned to combine ‘make’/intramural and ‘cooperation’ in their R&D investment.
- Relating knowledge sources to R&D strategies, UK manufacturers tended to use a number of market-based knowledge sources at the same time such as suppliers, clients, competitors, technical standards, industry associations. This knowledge-sourcing pattern was also associated with combining various forms of R&D strategies such as ‘make’ only, ‘make’ and ‘buy’, ‘buy’ and ‘cooperate’, and ‘make’, ’buy’ and ’cooperate’.
- Manufacturing firms engaged in cooperation with one national partner were also likely to report cooperation with other types of partners at national level.
- Meanwhile, those firms that participated in cooperation with overseas partners in one form were also more likely to engage in international cooperation in another form (more specifically, there was a noticeable clustering in the international cooperation with HEIs, government, consultants and competitors).

10. Concluding Remarks

The literature generally points to the importance of intangible investments in firms’ internal knowledge assets. Investments in in-house R&D and the share of R&D personnel have been traditionally considered as the main component of the internal knowledge assets; however recent evidence highlights the importance of other types of intangible investments. Although it is difficult to identify and measure the different types of intangible investments, a number of recent studies have attempted to develop measures using new data sets or new survey data (Borgo et al. 2012; Riley and

Robinson 2011; J Haskel et al. 2011), and further research should be undertaken to estimate the extent and importance of the soft side of innovation. A concept that is very closely linked to intangible assets is the notion of absorptive capacity, and our survey of the literature suggests that more direct measures of absorptive capacity would improve understanding of this area.

Accessing external knowledge is very important in determining productivity and competitiveness. Evidence suggests that UK firms are increasingly engaging in formal collaboration with different types of partners. The reviewed studies indicate that vertical linkages, through customers and suppliers are considered as the main sources of knowledge for innovation in UK firms. Firms that are more open to external collaboration are more likely to innovate and innovate better.

Firms can also benefit from knowledge developed by other firms and/or institutions without engaging in collaborative agreements or economic transactions. These are spillover effects, because the user who benefits does not pay the full economic cost of producing them. The review of the literature suggests that spillovers may vary in importance and occur through different routines. Trade appears to be an important channel of spillovers. There is some evidence on R&D spillovers via imports, and exporting is found to be associated with learning effects and higher productivity. Regarding FDI-spillovers, although foreign-owned firms are found to be more productive than their domestic counterparts, the empirical evidence reviewed is mixed. The positive impact of FDI-spillovers is closely linked to the domestic firms' absorptive capacity and the type of FDI.

Focusing on the spatial dimension of knowledge flows, the literature surveyed indicates a positive effect of being located in a cluster; however, studies reviewed present a mixed picture of local knowledge spillovers. There is some evidence on the importance of labour market dynamics and social interaction at the level of the individual in firms' and clusters' knowledge creation processes. However, the positive impact of knowledge spillovers seems to be closely dependent on sectoral and institutional characteristics.

The main mechanism of knowledge diffusion is through labour mobility. This finding highlights the importance of the tacit knowledge embedded in people. In this sense, clusters act as a hub for the attraction of global talents. High-technology clusters are found to be more likely to generate knowledge spillovers. However, the nature of the technology is closely related to the issues of intellectual property. Excessive non-disclosure agreements act as a barrier to knowledge diffusion. The regional science-base and university-industry interactions also arise as an important factor. Geographic proximity appears to facilitate personal interactions, however knowledge flows are not confined to geographical spaces; successful firms access knowledge regardless of its geographical location, through digital communication technologies. However, local and global networks should not be seen as conflicting, they both have important but different, sometimes complementary roles to play (Christopherson, Kitson, and Michie 2008). Successful clusters enable local firms to be embedded simultaneously in knowledge exchanges at different geographic scales.

Using data from four successive waves of the UKIS datasets spanning the 2002-2010 period, our empirical analysis shows that suppliers and clients represent the most important source of knowledge for innovation activities, with both manufacturing and other sectors making greater use of these than of institutional sources such as government and HEIs. Within the manufacturing sector those identified as being ‘high tech’ or ‘advanced manufacturing’ including Electrical Machinery, Medical etc. Instruments and Chemicals were the most inclined to use all sources of knowledge, including institutional sources. Comparing these knowledge linkages across regions, notably, the North West and the North East, Wales and Scotland seemed to suggest the strongest ties with government and HEIs.

In terms of measuring the sectoral variations in absorptive capacity, our results suggest that manufacturing, especially high-tech manufacturing, had the highest overall absorptive capacity (i.e. general external knowledge as the principal capacity). As to the absorptive capacity for national cooperation, Manufacturing and KIS sectors along with Agriculture and Utilities dominated the distribution of the absorptive capacity scores at the medium-range scores of the index although the difference was insignificant at other levels of the index. And there was little evidence of sectoral heterogeneity in the case of international cooperation. Within the manufacturing sector, our overall results suggest that high tech manufacturers had the strongest capacity for internalising and exploiting general external knowledge, followed by their medium-high tech counterpart; whereas the difference between the medium-low and low tech groups was often not very distinguishable.

Policy decisions made by government need to identify attributes which connect the most innovative firms. Within the manufacturing sector, our results from the multiple correspondence analysis indicate that product innovators are also likely to be process innovators, with more radical (‘blue sky’) innovators combining several streams and strategies together in their R&D investment.

Harris and Moffat (2012a) argue that for firms to perform better they need to mobilise their absorptive capacity to survive in difficult times. Therefore, understanding this process is also central to government when devising policy aiming to help firms survive and grow. They state:

“Having high levels of absorptive capacity (simply defined as the ability to exploit knowledge – obtained both internally and especially externally – that is embodied in intangible assets) is the way firms exploit their intangible assets, which largely define the dynamic capabilities that determine the firm’s competitive advantage. Through a combination of organisational routines and processes, firms must apprehend, acquire, share, assimilate, transform and exploit new knowledge in order to compete and grow in markets”.

The trend for greater cooperation in a globalised world is surely one that will increase and that the most dynamic and cooperative firms will reap rewards from it. There is evidence that manufacturers respond to external market conditions in their utilisation of knowledge sources. For example, the impact of the recent economic recession can be seen within the data sources in a decline in use of various knowledge sources in the 2006-2008 period before a graduated resurgence in the 2008-2010 period, suggesting that firms were making greater use of knowledge sources in times of uncertainty. HEIs and government sources remained relatively constant over time which suggests that firms with knowledge ties to these public institutions continued to do so independent of prevailing economic conditions. The challenge for industry will be to continue to make the best use of all sources of knowledge as economic conditions in the UK and abroad improve, across all parts of the UK.

Notes

1 In statistics, a meta-analysis refers to methods focused on contrasting and combining results from different studies, in the hope of identifying patterns among study results, sources of disagreement among those results, or other interesting relationships that may come to light in the context of multiple studies.

2 According to Outes-Leon and Dercon (2008), the pseudo R-squared from the estimated attrition probit model can be interpreted as the proportion of attrition that is non-random. In this instance, only some less than 2% of attrition is non-random and thus there is little evidence of substantial bias.

3 Data linking will be undertaken at the 'establishment' or 'reporting-unit' level to ensure comparability between the ARD and UKIS data.

4 For each element, respondents were asked to rank from 0 'not used', 1 'Low', 2 'Medium' to 3'High' importance. For the purpose of this report, these responses have been recoded to have two categories only, viz. used and not-used (i.e. we do not make distinctions in the level of importance).

5 Refer to Tables A4 and A5 in the Annex for a detailed classification of sectors.

6 Refer to Table A5 in the Annex for detailed definition of each grouping by their technology intensity.

7Admittedly, there seems to be some overlap between low and medium-low industries as evident in Figure 3 here and in subsequent analysis using this classification.

8 The UK has a strong aerospace sector with an international reputation. If the industry can maintain these strengths it is well placed to take advantage of the increased demand for air travel and rising demand for new aircraft as a result from rising per capita income across the world. International competition is marked by strong brands and Airbus, BAE Systems, Bombardier and Rolls Royce are key players in the global market with strong UK operations

9 The UK automotive sector is strongly export driven, with over 50% of total sales being exports. The future industry will be driven not only by economic factors but also by environmental drivers, which will force innovative changes in vehicles in terms of reducing emissions from combustion engines and hybrids and other non – fossil fuel alternatives. In common with aerospace, studies show that the automotive industry generates significant pull through for new goods and services from other areas within the economy.

10 Life sciences are a broad sector encompassing pharmaceuticals, medical technology and medical biotechnology. The sector is likely to be the beneficiary of high demand due to the simultaneously ageing population and increased incomes.

11 Respondents to the UKIS survey were asked to state whether the cooperation was UK regional, UK national, Other Europe, Other country. We have derived two broader categories pooling the UK national and the international options.

12 Refer to Table 5 for the variable names of these 26 elements.

13 Kaiser-Meyer-Olkin measure of sampling adequacy is employed to assess the value of input variables. Historically, the following labels are given to different ranges of KMO values: 0.9-1 Marvellous, 0.8-0.89 Meritorious, 0.7-0.79 Middling, 0.6-0.69 Mediocre, 0.5-0.59 Miserable, 0-0.49 Unacceptable.

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Annex

1. Overview of the studies on the rate of return of R&D – UK Evidence

Study	Sample	Period	Type of estimation	R&D rate of return
Bond, Harhoff, & Reenen, 2003	239 firms	1988-1996	GMM-SYS (pooled)	38%
Bond et al. 2003	239 firms	1988-1996	Sectoral level	20%
R Griffith et al. 2006	188 mfg firms	1990-2000	GMM -SYS	11%*
R Griffith et al. 2006	188 mfg firms	1990-2000	VA Production function (pooled)	14%*
Rogers 2009	719 firms	1989-2000	VA Production function with R&D flow as input (pooled)	40% to 58% (mfg) 53% to 108% (non-mfg)**

*Computed assuming means of medians of the variables.
**Capital and labor corrected for double counting

Table A.2. Overview of the studies on FDI spillovers – The UK Evidence

Study	**Spillovers Effects**	**Period**	**Data**	**Aggregati on level**	**Result**
Driffield, 2001	Productivity	1989-1992	cross-section	Industry	+
Girma, Greenaway, & Wakelin, 2001	Productivity	1991-1996	panel	Firm	?
Girma et al., 2001	Productivity	1980-1992	panel	Firm	?
Harris & Robinson, 2004	Productivity	1974-1995	panel	Firm	?
Girma & Wakelin, 2000	Productivity	1988-1996	panel	Firm	?
Haskel, Pereira, & Slaughter, 2002	Productivity	1973-1992	panel	Firm	+/?
Girma, 2005	Productivity	1989-1999	panel	Firm	?
Girma & Görg, 2003	Productivity	1980-1992	panel	Firm	?
De Propris & Driffield, 2005	Productivity	1993-1998	panel	Firm	-
Driffield & Love, 2007	Productivity	1987-1997	panel	Firm	+
Driffield, Munday, & Roberts, 2002	Productivity	1984-1992	panel	Industry	Horizontal: ? Backward: ? Forward: +
Harris & Robinson, 2003	Productivity	1974-1995	panel	Firm	Horizontal: ? Backward: ? Forward: ?
Girma et al., 2001	Wage	1991-1996	panel	Firm	?
Driffield & Girma, 2003	Wage	1980-1992	panel	Firm	?
Greenaway, Sousa, & Wakelin, 2004	Export	1992-1996	panel	Firm	+

Table A3: Attrition probit model to determine attrition bias in UKIS 2011

Dependent variable: non attrition (valid in usable sample)	$\hat{\beta}$	SE
Employment	-0.000**	(0.000)
Weight	-0.006***	(0.001)
Food, drink, tobacco	-0.055	(0.104)
Textiles	-0.028	(0.151)
Clothing, leather & footwear	-0.206	(0.192)
Wood products	-0.054	(0.153)
Paper	0.251	(0.171)
Publishing & printing	-0.108	(0.110)
Chemicals	0.047	(0.129)
Rubber & plastics	0.138	(0.117)
Non-metallic minerals	-0.156	(0.142)
Basic metals	0.399**	(0.202)
Fabricated metals	0.044	(0.097)
Machinery & equipment nes	0.162	(0.107)
Electrical machinery	-0.062	(0.117)
Medical etc instruments	0.187	(0.142)
Motor & transport	-0.057	(0.110)
Furniture & manuf nes	-0.192	(0.118)
Construction	-0.095	(0.082)
Sale/repair motors	0.042	(0.094)
Wholesale trade	0.085	(0.082)
Dependent variable: non attrition (valid in usable sample)	$\hat{\beta}$	**SE**
Retail	-0.142*	(0.085)
Hotels and restaurants	-0.217***	(0.082)
Transport	-0.370***	(0.094)
Transport support	0.002	(0.116)
Post & telecom	0.109	(0.124)
Financial	-0.315***	(0.095)
Real estate	-0.170*	(0.092)
Machine rentals	-0.342***	(0.121)
Computing	-0.057	(0.100)
R&D	-0.073	(0.105)
Other business	-0.101	(0.077)
Film etc services	-0.236*	(0.139)
Eastern England	0.055	(0.056)
London	-0.295***	(0.050)
North East England	-0.045	(0.072)
North West England	-0.324***	(0.052)
Northern Ireland	-0.207***	(0.068)
Scotland	-0.028	(0.057)
South East England	-0.027	(0.051)
South West England	-0.028	(0.057)
Wales	0.083	(0.069)
West Midlands	0.004	(0.057)
Yorks & the Humber	-0.021	(0.057)
Constant	0.611***	(0.084)

No. of observations	14,342
Pseudo R-squared	0.020
Log likelihood	-9225.48
Likelihood-ratio test of joint significance $^{2}(13)$	106.86 ***

Data source: UKIS 2011

Notes: *** significant at better than 1% level, ** significant at better than 5% level, * significant at better than 1% level

Table A4: Sectoral structure used in the analysis

Sectors	
Agriculture, forestry and fishing (Sections A, B, E), recycling	
Mining and quarrying (Section C)	
Manufacturing (Section D)	
▪ Food, drink, tobacco	
▪ Textiles	
▪ Clothing, leather & footwear	
▪ Wood products	
▪ Paper	
▪ Publishing & printing	
▪ Chemicals	
▪ Rubber & plastics	
▪ Non-metallic minerals	
▪ Basic metals	
▪ Fabricated metals	
▪ Machinery & equipment nes	
▪ Electrical machinery	
▪ Medical etc instruments	
▪ Motor & transport	
▪ Furniture & manuf nes	
Construction (Section F)	
Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods (Section G)	
Services (Sections H, I, J, K, L, M, N, O, P)	
o Knowledge-intensive services (KIS)	o Less Knowledge-intensive Services (LKIS)
▪ Water transport, Air transport	▪ Hotels and restaurants (Section H)
▪ Telecommunications	▪ Land transport; transport via pipelines
▪ Financial intermediation (Section J)	▪ Supporting/auxiliary transport; travel agencies
▪ Computer and related activities	▪ Post and courier activities
▪ Research and development	▪ Real estate activities
▪ Legal, accounting, book-keeping and auditing activities; tax consultancy; market research and public opinion polling; business and management consultancy holdings	▪ Renting of machinery and equipment without operator and of personal and household goods
▪ Architectural and engineering activities and related technical consultancy	▪ Industrial cleaning
▪ Technical testing and analysis	▪ Miscellaneous business activities n.e.c.
▪ Advertising	▪ Activities of membership organisations n.e.c.
▪ Labour recruitment and provision of personnel	▪ Other service activities
▪ Investigation and security activities	▪ Private households with employed persons (Section P)
▪ Public administration and defence; compulsory social security (Section L)	▪ Extra-territorial organisations and bodies (Section Q)
▪ Education (Section M)	
▪ Health and social work (Section N)	
▪ Recreational, cultural and sporting activities	
▪ Water transport, Air transport	

Table A5: OECD classification of industries by technology intensity *

High tech manufacturing	Pharmaceuticals Computers and Office Machinery Electronics and Communications Medical, precision and Optical Instruments Aerospace
Medium-high tech manufacturing	Chemicals Non Electrical machinery Electrical Machinery Motor Vehicles Other transport equipment
Medium -low tech manufacturing	Petroleum Refining Rubber and Plastic Products Non Metallic Mineral Products Non ferrous Metals Fabricated Metal Goods Shipbuilding
Low tech manufacturing	Food Products and Tobacco Wood , Textiles and Furniture Paper and Printing, recorded media Wood, Textiles and Furniture

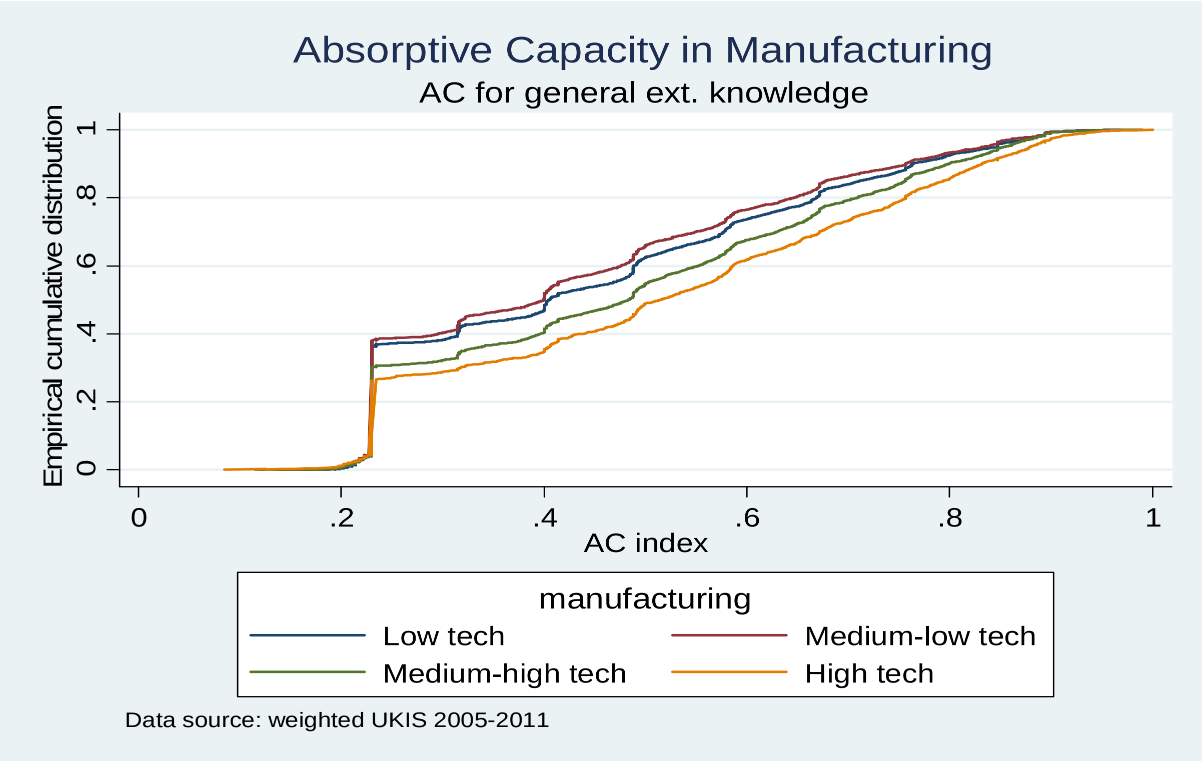
*Refer to Annex1 in the OECD publication on Science, Technology and Industry Scoreboard (2003) for more details

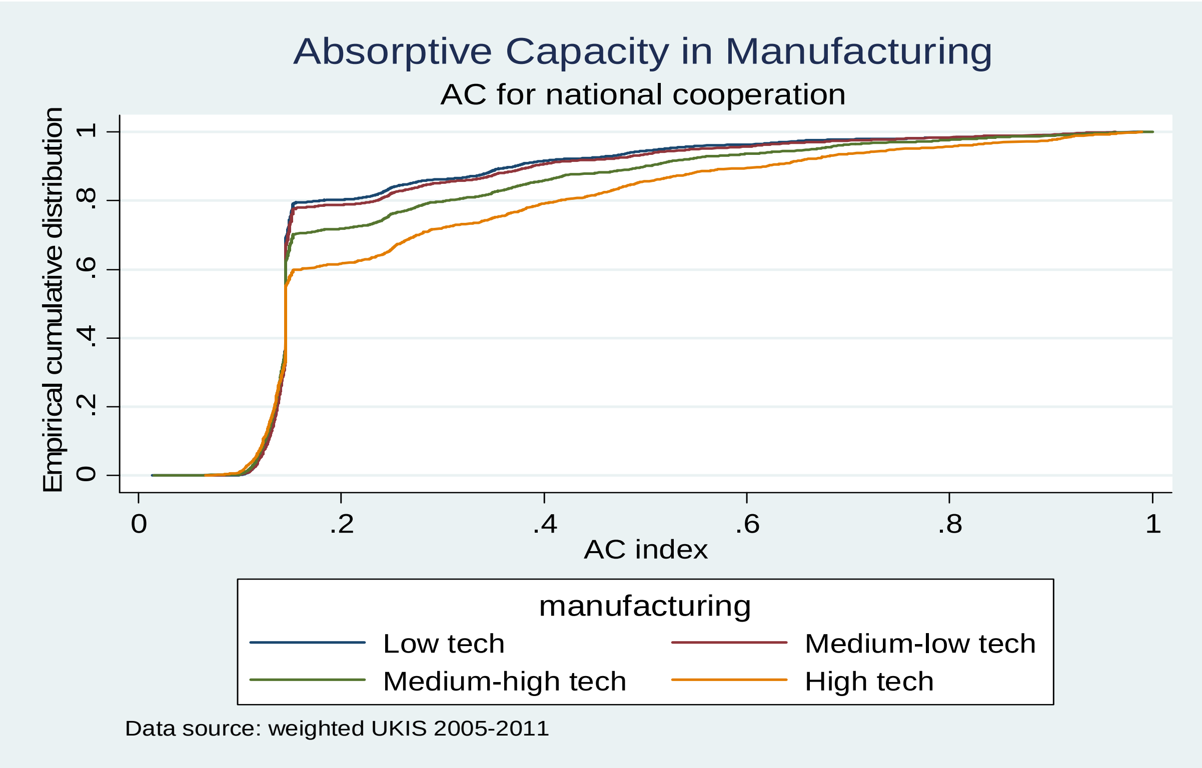
Table A6: Average absorptive capacity indices, all sectors, 2002-2010

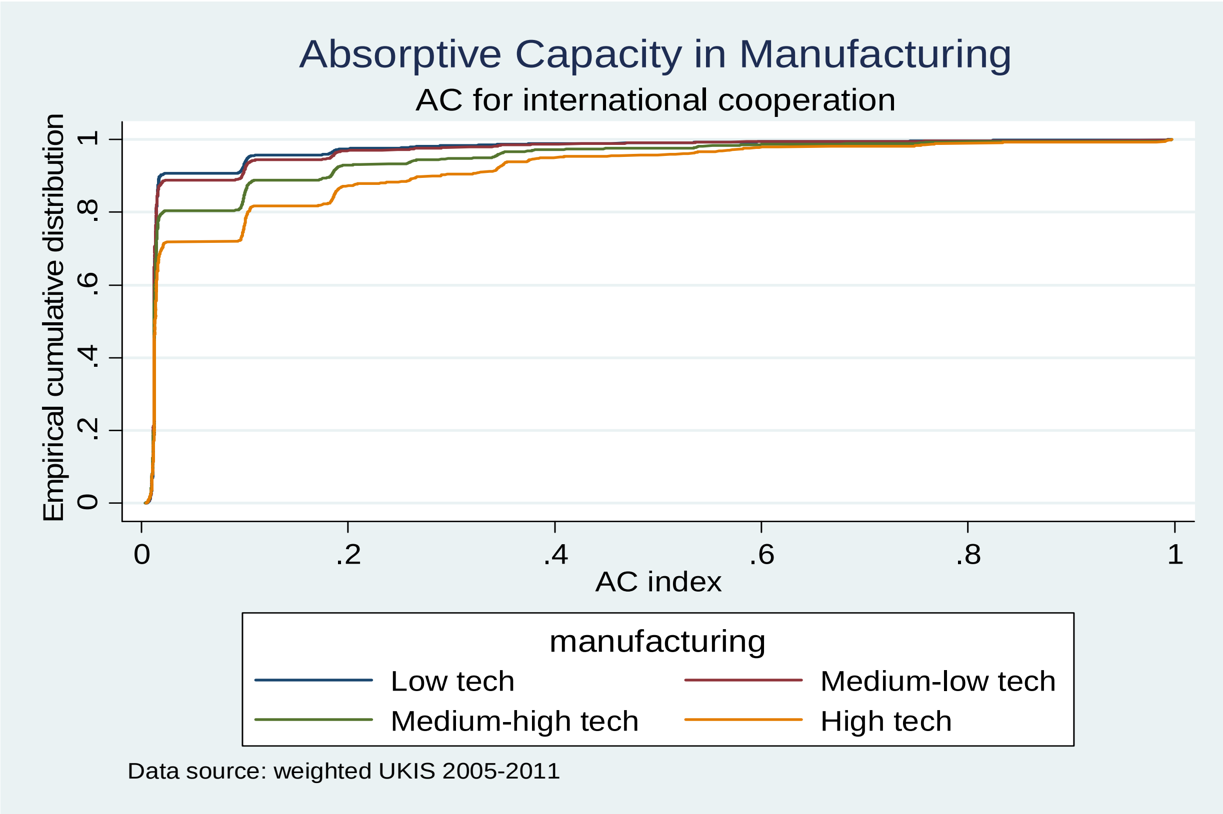
Sector	General external knowledge	National co-operation	International co-operation	Business strategy and practice	Specialist knowledge from HEIs/government
Agriculture, Utilities	0.404	0.202	0.023	0.257	0.319
Mining, Quarrying	0.388	0.183	0.038	0.207	0.318
Manufacturing	0.433	0.201	0.035	0.250	0.298
Construction	0.362	0.175	0.016	0.185	0.300
Wholesale, Retail	0.382	0.184	0.026	0.202	0.291
Services-LKIS	0.351	0.176	0.023	0.192	0.294
Services-KIS	0.419	0.201	0.037	0.272	0.311
Mean	0.390	0.188	0.028	0.222	0.298

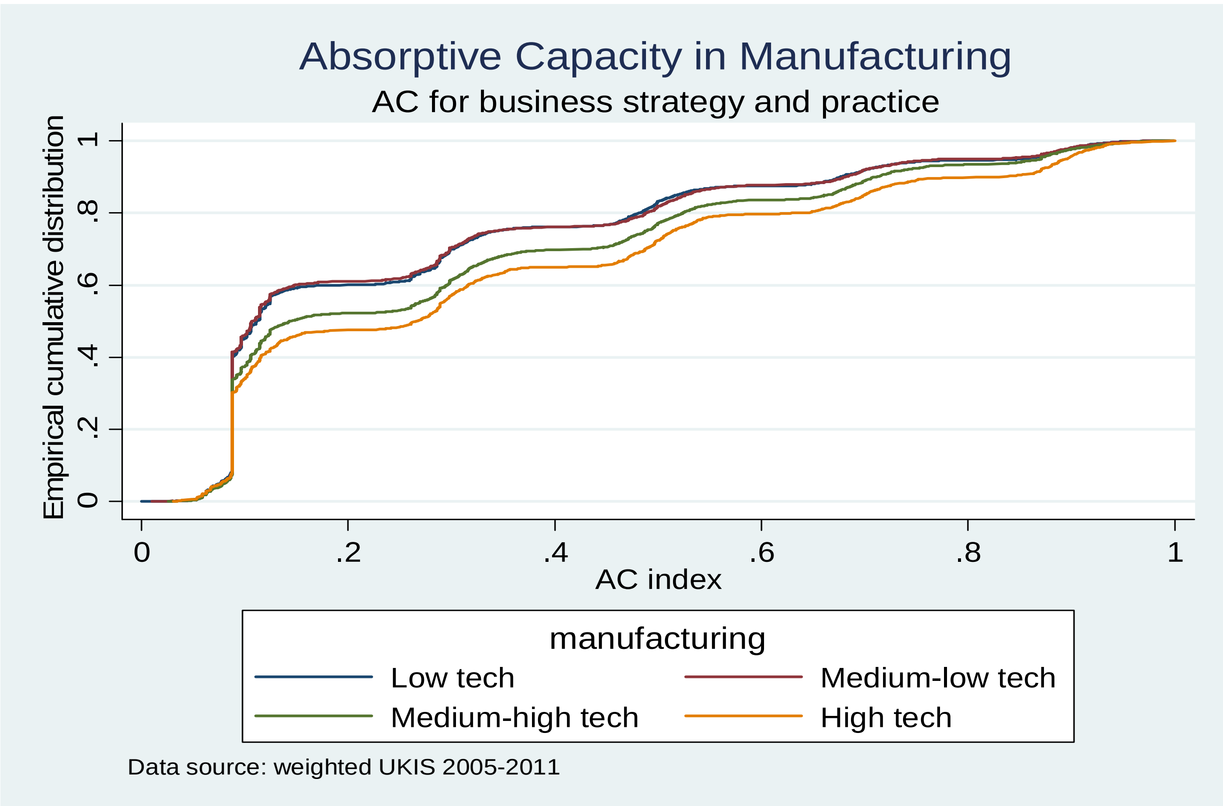
Source: weighted UKIS 2005-2011

Figure A1: Empirical cumulative distribution of absorptive capacity indices in manufacturing firms by technology intensity, 2002-2010






Absorptive Capacity in Manufacturing
AC for international cooperation
Empirical cumulative distribution
0
.2
.4
.6
.8
1
AC index
manufacturing
Low tech
Medium-low tech
Medium-high tech
High tech
Data source: weighted UKIS 2005-2011


Absorptive Capacity in Manufacturing
AC for business strategy and practice
Empirical cumulative distribution
0
.2
.4
.6
.8
1
AC index
manufacturing
Low tech
Medium-low tech
Medium-high tech
High tech
Data source: weighted UKIS 2005-2011

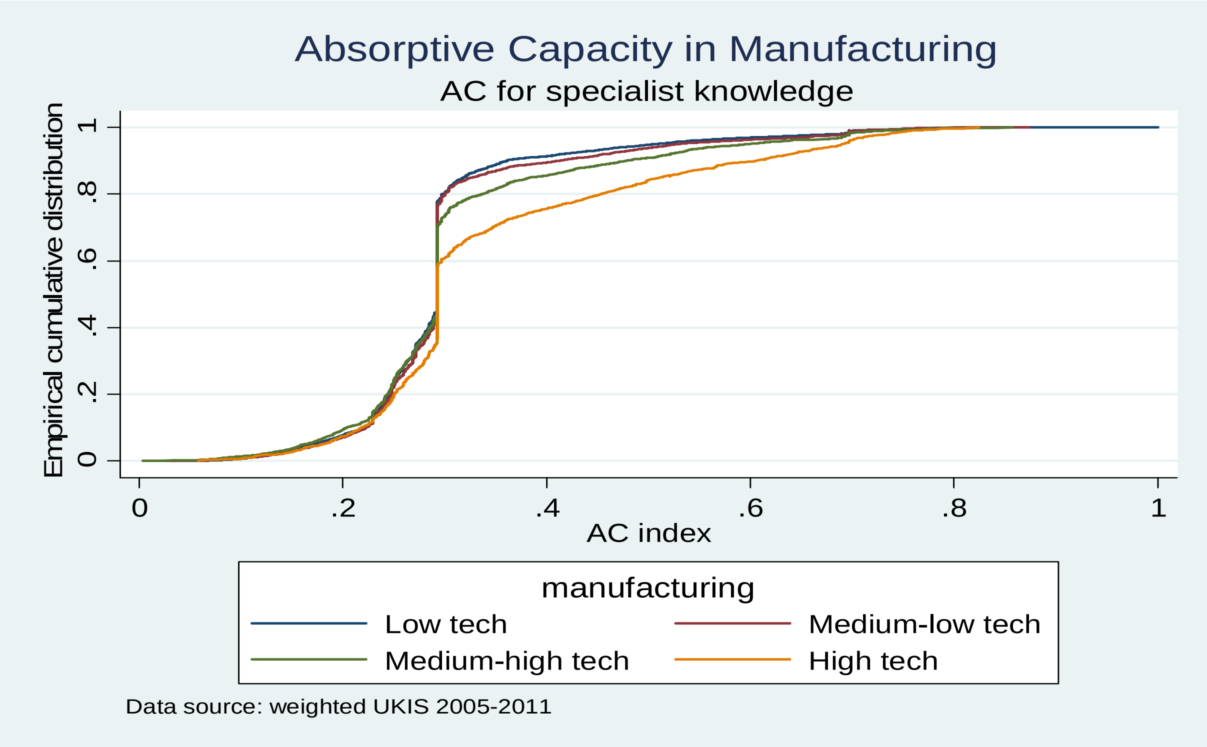

Absorptive Capacity in Manufacturing
AC for specialist knowledge
Empirical cumulative distribution
0
.2
.4
.6
.8
1
AC index
manufacturing
Low tech
Medium-low tech
Medium-high tech
High tech
Data source: weighted UKIS 2005-2011

Table A7: Average absorptive capacity indices in manufacturing firms by UK government office region, 2002-2010

GOR regions	General external knowledge	National co-operation	International co-operation	Business strategy and practice	Specialist knowledge from HEIs/government
East Midlands	0.430	0.198	0.029	0.249	0.295
Eastern England	0.449	0.199	0.038	0.254	0.299
London	0.421	0.192	0.030	0.253	0.296
North East	0.429	0.204	0.036	0.273	0.302
North West	0.427	0.208	0.037	0.243	0.301
Northern Ireland	0.441	0.192	0.034	0.241	0.315
Scotland	0.448	0.195	0.033	0.256	0.301
South East	0.441	0.203	0.044	0.258	0.295
South West	0.439	0.201	0.036	0.247	0.292
Wales	0.452	0.209	0.039	0.260	0.308
West Midlands	0.417	0.205	0.030	0.244	0.297
York’s & Humber	0.428	0.200	0.033	0.242	0.294
Mean	0.434	0.201	0.035	0.250	0.298

Source: weighted UKIS 2005-2011