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ABSTRACT

External partnerships play an important role in firms' acquisition of the knowledge inputs to innovation. Such partnerships may be interactive – involving exploration and mutual learning by both parties – or non-interactive – involving exploitative activity and learning by only one party. Examples of non-interactive partnerships are copying or imitation. Here, we consider how firms' innovation objectives influence their choice of interactive and/or non-interactive connections. Four empirical results emerge. First, we find strong and consistent support for complementarity between non-interactive and interactive connections across firms in all sectors and sizebands. Second, we find that innovation objectives related to new products and services are linked only to non-interactive connections. Third, we find tentative evidence that where firms have innovation objectives which relate to product or service improvement they are more likely to establish non-interactive rather than interactive connections. Fourth, the extent of firms' interactive and non-interactive connections are strongly related firms' human capital endowments. These latter results suggest interesting second-order innovation effects from human capital improvements.

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1. INTRODUCTION

Innovation partnerships have a long history. James Watt, the steam engine pioneer, was only able to bring his innovation to market because of financial and engineering backing from his partner Matthew Boulton, and specialist expertise in cylinder manufacture from the firm owned by John Wilkinson. More recent evidence suggests the importance of partnerships in innovation for stimulating creativity, reducing risk in the innovation process, accelerating or upgrading the quality of the innovations made, and signalling the quality of firms' innovation activities (Powell 1998). Innovation partnerships may also increase firms' access to technology developed elsewhere (Mowery, 1990; Niosi, 1999) and their ability to appropriate the returns from innovation (Gemser and Wijnberg, 1995). Moreover, having more extensive networks of partners is likely to increase the probability of obtaining useful knowledge from outside of the firm (Leiponen and Helfat 2010) and increase the probability that this will be complementary with aspects of firms' internal knowledge base (Roper et al. 2008).

In this paper we consider the reasons why firms' establish external connections of different types as part of their innovation activity. Firms may of course decide not to innovate, or to innovate on the basis of proprietary knowledge developed purely within the firm. While this type of independent technological development strategy has been linked to the success of some groups of firms (Simon 1996), it is increasingly uncommon among innovative smaller firms (van de Vrande et al. 2009). Where a firm does decide to establish external connections to acquire knowledge for innovation it has a number of choices relating to the nature of those connections. Should the firm develop collaborative or interactive connections with partners to jointly develop new knowledge? Or, should the firm adopt non-interactive, imitation or copying strategies (Glückler 2013)? These choices may reflect the fact that interactive and non-interactive knowledge search strategies may provide different types of knowledge and provide the basis for different types of innovation. Here, we argue that interactive knowledge search strategies, involving collaborative or co-

operative innovation, may allow exploratory knowledge co-creation leading to transformational, new-to-the-world innovation. Such interactive partnering approaches may also have uncertain outcomes but may help firms to share the risks and costs implicit in innovation. Non-interactive knowledge search strategies, on the other hand, inevitably involve less technical and commercial uncertainty - as the market value of the imitated knowledge is already established. Such activities emphasise the exploitation of pre-existing knowledge through more incremental innovation.

But what determines why firms choose either interactive or non-interactive innovation connections, or both? Some elements of this question have been discussed elsewhere with a focus on the role of firms' internal capabilities and structure in shaping firms' knowledge acquisition strategies. Absorptive capacity, for example, typically measured using R&D and human capital measures, has been shown to play a significant role in shaping firms' ability to take advantage of external knowledge (Spithoven, Clarysse, and Knockaert 2011; Moon 2011). Xia and Roper (2014) also identify a positive relationship between realised absorptive capacity and the extent of partnering activity of small bio-technology firms. In a related study, Freel and Aslesen (2013) consider the role of organisational structure on firms' partnering strategies, providing evidence that less hierarchic firms develop more diverse connections, and that team or project-based working may be particularly conducive to the development of deep or strong links between firms. A similar study by (Moon 2011) links the breadth of firms' (interactive) knowledge search activities to their use of IP protection.

Existing research on the determinants of firms' knowledge acquisition strategies has three main limitations which we seek to address here. First, existing studies focus predominantly on interactive knowledge acquisition strategies through innovation partnering, paying less attention to the potential value of non-interactive knowledge sourcing mechanisms such as imitation or copying. Here, we consider separately the determinants of interactive and non-interactive knowledge acquisition strategies, which may

have very different characteristics and therefore implications for innovation (Glückler 2013). Secondly, existing studies tend to focus on firm characteristics such as R&D, skills and organisational structures and their implications for external knowledge acquisition (Freel and Aslesen 2013; Spithoven, Clarysse, and Knockaert 2011). Here, following Moon (2011), we argue that firms' innovation strategic objectives may also be important in shaping firms' knowledge acquisition strategies. Thirdly, we examine size and sectoral differences, recognising that the rationale for external knowledge search may differ significantly between larger and smaller companies and between different sectors (Moon 2011; Vahter, Love, and Roper 2013). Vahter et al. (2013) argue, for example, that external knowledge search is of more value for smaller companies due to their weaker internal knowledge base.

2. CONCEPTUAL FRAMEWORK AND HYPOTHESES

2.1 Firms' innovation objectives

Discussions of firms' innovation objectives typically reflect the diversity of firms' innovation activities, the relative risks and rewards of each type of innovation, and the need to balance resources and capabilities across different activities. Three distinct, although strongly inter-related, perspectives can be identified within the research literature. First, scholars in the innovation studies literature have discussed the distinction between innovation-based and imitation-based strategies (Shenkar 2010; Schnaars 1994; Bolton 1993). Both may involve the introduction of new products or services to the market, with innovation-based strategies involving new-to-the-market innovations, while imitations are new products or services, which are new-to-the-firm but now new-to-the-market. Imitation may, of course, be of very different types ranging from licensed or unlicensed (counterfeit) copying of a product or service, through mimic products which copy some or all of the features of an innovative product or service, to products which emulate an existing product but may actually be better than the established market leader (Ulhoi 2012).

Innovation-based and imitation-based strategies have very different risks and rewards. Innovation may create first-mover advantages for the innovating firm. These may lead to higher returns from a desirable and unique product or service but may also have other advantages in terms of helping the first mover to learn rapidly about the markets and build brand loyalty among customers (Kopel and Loffler 2008)[1]. For imitators on the other hand the potential for 'second mover advantages' are also evident. Perhaps the key advantage for imitators is that the market leader has already taken much of the uncertainty out of the initial product or service introduction[2]. On the production side this may mean that the imitator can copy, emulate or reverse engineer the product design or service delivery of an innovator. On the demand side, the imitator can learn from the innovator about consumers' appetite for a particular product or service and what consumers are prepared to pay. The imitator's problem however is not always simple as they try to establish a position in a market share in which there is already at least one established player (Ulhoi 2012). Second mover advantages can certainly occur at a firm level and there is some evidence – particularly in less dynamic markets – that imitation may be a more profitable strategy than innovation (Lieberman and Asaba 2006)[3].

[1] A key issue for innovators in any market place, however, is their ability to sustain their position of market leadership. In some sectors – biotechnology or engineering – this may involve formal strategies such as patenting to protect intellectual property; in other sectors more strategic approaches may be adopted such as frequent changes or upgrades to product or service design. Aggressive pricing also provides a way in which market leaders may protect any first mover advantages (Ulhoi 2012).

[2] Imitation may also be a stepping stone towards innovation as firms build innovative capabilities. This process is perhaps clearest in developing economies where firms have steadily developed their R&D and creative competencies. On Korea see (Kim 1997), on Taiwan (Hobday 1995), on China (Lim and Kocaoglu 2011) and on Brazil, (Dorion, Pavoni, and Chalela 2008).

[3] Imitation – second-mover - strategies may provide individual firms with a less risky option than innovation. At an industry and social level, however, imitation can have either positive or negative effects. On the positive side imitation may help to maximise the social and consumer benefits of the original innovation by making products or services available to more consumers. Imitation may also have negative effects, however, by reducing the variety of products or services within a market and increasing the collective vulnerability to external competition (Lieberman and Asaba 2006).

While discussion of firms' innovation objectives in the innovation studies literature has tended to focus on the nature of the innovation itself – i.e. the innovation versus imitation distinction – discussion in the strategy literature has adopted a more contingent perspective, integrating the nature of firms' innovation with their capabilities and market position. Nagji and Tuff (2012), for example, make a distinction between: core innovation (incremental changes which optimise existing products for existing customers); adjacent innovation; and transformational or new-to-the-market innovations. Such transformational innovation involving the introduction of technologically innovative products can have a positive effect on business performance (Xin, Yeung, and Cheng 2010), and also facilitate entry to new export markets (Ganotakis and Love 2011) and market share (Lee and Kim 2013). Core innovation, on the other hand, is more to do with delivering increased value to existing customers through quality improvements, price reductions or performance improvements (Banbury and Mitchell 1995).

Innovation strategy may also involve process innovations which yield significant performance gains to the innovating firm (Rasiah, Gopal, and Sanjivee 2013). Strategies involving the adoption of advanced management techniques (AMTs), for example, may enable firms to develop more flexible and adaptive production systems allowing smaller batch sizes and enabling firms to cope better with perceived environmental uncertainty (Hofmann and Orr 2005; Zammuto and Oconnor 1992), changes to regulation etc. More flexible production systems may also allow firms to adopt more complex innovation strategies with potentially higher returns (Hewitt-Dundas 2004). Process innovation may also facilitate more radical innovation strategies as firms seek to create market turbulence by engaging in disruptive innovation in order to establish a position of market or technological leadership (Anthony et al. 2008; Hang, Chen, and Subramian 2010).

Views differ however on the potential for developing strategic recipes for the optimal balance between core, adjacent and transformational innovation with (Nagji and Tuff 2012, p. 66) remarking that 'outperforming

firms typically allocate about 70% of their innovation resources to core offerings, 20% to adjacent efforts and 10% to transformational initiatives'. On the other hand, Davila et al. (2006), p. 59, remark: 'There is no menu of generic innovation strategies from which to choose. Each company's management team has to craft its own innovation strategy, adapt to changing conditions and choose the right time to make key moves … The innovation strategy must support the business strategy'. Davila et al (2006), however, do diffferentiate between 'play-to-win' strategies which place an emphasis on adjacent and transformational innovation, and 'play-not-to-lose' strategies which emphasise more incremental, core, innovation[4].

A third perspective – grounded in the literature on organisational learning – makes a distinction between the exploratory and interactive process involved in the development of more radical innovation and the more exploitative process underlying incremental innovation, viz: 'exploitative innovation strategies primarily build on improvements and refinements of current skills and processes and lead to incremental product changes … Exploratory innovation primarily involves the challenging of existing approaches … Outcomes of exploratory innovation strategies are superior new products with significant consumer benefits: they can enable the firm to enter or even create new markets' (Mueller, Rosenbusch, and Bausch 2013, p. 1607).

2.2 Knowledge acquisition for innovation

We can identify two main strategic mechanisms through which firms may access, absorb and use external knowledge, and which may influence their innovation activity[5]. First, firms may form deliberate, purposive connections with other firms or organisations as a means of acquiring or accessing new

[4] We might also suggest a 'choose-not-to-play' strategy in which for whatever reason firms' decide not to invest in innovation in a given period. Innovation survey data typically suggest a significant minority of firms fall into this category.

[5] Firms may also acquire knowledge vicariously and unintentionally through informal spill-over mechanisms such as social contacts between employees and those in other firms, media publicity or demonstration effects, or through the mobility of labour between enterprises. These pure knowledge spill-overs represent un-priced gains to the firm, effectively increasing the social returns to knowledge (Beugelsdijck and Cornet 2001).

knowledge. These might be partnerships, network linkages or contractually-based agreements entered into on either a formal or informal basis. This type of connection is characterised by strategic intent and mutual engagement of both parties, and may be characterised as a form of interactive learning (Glückler 2013). Second, firms might acquire knowledge deliberately but without the direct engagement of another party. Examples of this type of mechanism include imitation, reverse engineering or participation in network or knowledge dissemination events. Here, there is a clear strategic intent on the part of the focal firm but no mutuality in the learning process, and this may be characterised as non-interactive learning. For example, in their analysis of university-business connections (Hewitt-Dundas and Roper 2011) distinguish between knowledge connections 'characterised by a two-way flow of knowledge, e.g. through formal or informal joint ventures or collaborative R&D projects', and knowledge suppliers 'characterised by a more uni-directional transfer of knowledge'.

Interactive learning is initiated by firms' strategic decision to build links and connections with other firms and economic actors (e.g. research institutes, universities and government departments) to capitalise on the knowledge of the linked parties, co-operate with the linked parties, and/or to exploit the knowledge together (Borgatti and Halgin 2011). Three characteristics seem important in measuring the potential benefits of interactive learning: the number of connections the firm has; the mode of interaction adopted; and the nature of the embeddedness of the networks in which firms are involved (Borgatti and Halgin 2011; Glückler 2013).

At its simplest, interactive learning and knowledge acquisition can be positively affected by a firms' number of connections. In purely statistical terms, since the payoff from any given innovation connection is unknown in advance, the chances of obtaining benefit from any connection in a given distribution of payoffs increases as the number of connections increases (Love et al, 2014). Having more connections increases the probability of obtaining useful external knowledge that can be combined with the firm's

internal knowledge to produce innovation (Leiponen and Helfat 2010). The extent or breadth of a firm's portfolio of external connections may also have significant network benefits, reducing the risk of "lock-in" where firms are either less open to knowledge from outside its own region (Boschma 2005), or where firms in a region are highly specialised in certain industries, which lowers their ability to keep up with new technology and market development (Camagni 1991). However, the capacity of management to pay attention to and cognitively process many sources of information is not infinite, since the span of attention of any individual is limited (Simon 1947). This attention issue means that while the returns to additional connections may at first be positive, eventually the firm will reach a point at which an additional connection actually serves to diminish the innovation returns of external networking (Laursen and Salter 2006; Leiponen and Helfat 2010; Grimpe and Sofka 2009; Garriga, von Krogh, and Spaeth 2013).

Non-interactive learning is characterised by the absence of reciprocal knowledge and/or resource transfers between actors. The most frequently discussed modes of non-interactive learning are: imitation, where a firm absorbs the knowledge of other actors through observation of the actions/behaviour of the source actor; reverse engineering, where a firm derives knowledge from the final product of another firm, obtained from the market or through supply chain interaction; and the codification of knowledge, where a firm obtains knowledge through knowledge which is a public good such as news, patents and regulations etc. (Glückler 2013). As with interactive connections, the chances of obtaining useful knowledge from any non-interactive connection will increase as the number of non-interactive connections increases. Or, put another way, having more non-interactive connections will increase the probability of obtaining useful external knowledge.

The contrasting nature of the learning processes involved in interactive and non-interactive connections, and consequent differences in the types of knowledge they generate, suggests the potential for a complementary relationship. Two groups of alternative explanations for this

complementarity are possible relating to the contrasting functional contents of each type of connection and/or their management and co-ordination. First, in terms of connection content, it may be that the different types of learning processes - exploratory and exploitative – implicit in interactive and non-interactive connections generate knowledge which plays a complementary role in firms' innovation activity. Collaborative connections with universities or research centres, for example, may facilitate exploratory activity, while non-interactive connections with customers or equipment suppliers may contribute more directly to exploitation (Faems et al. 2010; Lavie and Rosenkopf 2006). Second, there may be economies of scope as firms learn how to better manage and co-ordinate their external connections (Love, Roper, and Vahter 2014). This leads to the first hypothesis:

Hypothesis 1: Interactive and non-interactive connections are complementary elements of firms' knowledge acquisition strategies.

2.3 Innovation strategy and knowledge acquisition

The knowledge necessary for successful innovation includes technical, commercial and market data, both codified and tacit. The types of knowledge needed will, however, depend significantly on the technological novelty, the focus of the innovation (i.e. product, service, process) and the stage of development of any innovation. Developing new-to-the-market innovations, for example, is likely to involve exploratory R&D activity and the development of new technological knowledge either by a firm itself or through an external connection. Such partnership projects have a number of potential advantages – speed, risk sharing, access to a broader resource base – which can increase innovation quality and ameliorate both technological and commercial risk (Astebro and Michela 2005). Here, there is likely to be mutual learning as innovation partners interact to generate new knowledge. This suggests:

Hypothesis 2: Interactive connections will be most important where firms' innovation objectives emphasise new product or service innovation

Alternative knowledge acquisition strategies are non-interactive, involving mechanisms such as copying, imitation, or the purchase of intellectual property through mechanisms such as licensing (Anand and Khanna 2000). In each case the emphasis is on the exploitation of existing knowledge. Such exploitative, non-interactive mechanisms may, however, allow firms to rapidly establish positions in new technical areas without undertaking a discovery process, and to avoid both the technological and commercial uncertainties implicit in such a process. A recent Korean study, for example, suggested that: 'technology acquisition may be one of the most efficient collaborative activities when this activity can be simply conducted to complement insufficient resources' (Suh and Kim 2012, p. 361). Ulhoi (2012) outlines the range of outcomes which may arise from non-interactive imitation strategies: Replica – licensed or unlicensed (counterfeit) copying of a product or service; Mimicry – copying some or all of the features of an innovative product or service; Analogue – developing a different product or service but with similar functionality. The implication is that:

Hypothesis 3: Non-interactive connections will be most important where firms' innovation objectives emphasise product or service improvement.

Different types of innovation – product, process or service – will also require different types of knowledge (Roper, Du, and Love 2008). Connections with knowledge search among customers, for example, might impact most strongly on product innovation (Su, Chen, and Sha 2007), while search with suppliers or external consultants might impact most directly on process change (Horn 2005; Smith and Tranfield 2005). The majority of process change is likely to be incremental and "firms frequently rely on machinery suppliers and outside consultants as sources of embodied process innovation, the challenges posed by change can draw on a a variety of technical sources with different knowledge bases and aims" (Robertson, Casali, and Jacobson 2012, p. 822). Therefore we might argue that:

Hypothesis 4: Non-interactive connections will be most important where firms' innovation objectives emphasise process innovation

3. DATA AND METHODS

Our analysis is based on four waves of the UK Innovation Survey, the UK counterpart of the EU Community Innovation Survey, covering the period 2004 to 2010. Each survey was conducted by post using as a sampling frame the Interdepartmental Business Register, with structuring by sizeband, region and sector. Surveys were non-compulsory and achieved response rates ranging from 51.1 per cent in CIS7 (2010) to 58 per cent in CIS4 (2004). The UK innovation surveys provide detailed information on firms' innovation activity, an indication of the objectives of firms' innovation activity and their external innovation connections. In addition the surveys provide information on a range of other workplace level characteristics which we use as control variables[6].

To measure the extent of firms' interactive knowledge search activity we define a measure which relates to the number of innovation partner types with which each firm was working (wherever they were located)[7]. In the UK Innovation Survey we find the following question: 'Which types of cooperation partner did you use and where were they located?.' Seven partner types are identified: other enterprises within the group; suppliers of equipment, materials, services or software; clients or customers; competitors within the industry or elsewhere; consultants, commercial labs or private R&D institutes; universities or other higher education institutions; government or public research institutes. Our indicator of the extent of firms' interactive knowledge search therefore takes values between 0, where firms had no innovation partners, and 7 where firms were collaborating with all partner types identified. On average firms were working with an average of 1.6 interactive types (Table 1).

[6] Definitions used in the UK innovation survey accord to the OECD Oslo manual guidelines.

[7] This measure of the 'breadth' of search activity has been used extensively in studies of the determinants of innovation (Laursen and Salter 2006) and in prior studies of the determinants of 'openness' (Moon 2011).

Table 1: Descriptive Statistics

	All			Small			Medium			Large		
Variable	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
Interactive	15,866	1.62	2.09	7,272	1.39	1.97	4,431	1.62	2.04	4,146	2.02	2.29
Non-interactive	15,866	1.54	1.43	7,272	1.37	1.37	4,431	1.58	1.42	4,146	1.78	1.49
New product/service objective factor	15,866	0.79	0.33	7,272	0.79	0.34	4,431	0.80	0.33	4,146	0.80	0.33
Improved product/service objective factor	15,866	0.74	0.30	7,272	0.72	0.31	4,431	0.75	0.30	4,146	0.78	0.28
Process innovation objective factor	15,866	0.69	0.36	7,272	0.67	0.37	4,431	0.69	0.36	4,146	0.72	0.34
Control variables												
Employment	15,866	353.74	2,544.23	7,272	21.45	10.59	4,431	106.81	50.38	4,146	1,200.88	4,878.12
Exporter	15,866	0.52	0.50	7,272	0.45	0.50	4,431	0.58	0.49	4,146	0.58	0.49
% of science graduates	15,866	10.18	19.54	7,272	11.48	22.00	4,431	9.11	17.51	4,146	9.04	16.64
% of other graduates	15,866	11.01	19.11	7,272	10.56	19.61	4,431	11.15	18.73	4,146	11.64	18.63
R&D	15,866	0.88	0.33	7,272	0.87	0.33	4,431	0.89	0.32	4,146	0.87	0.34

Table 1: Descriptive Statistics (contd.)

	Manufacturing			Services		
Variable	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.
Interactive	6,325	1.65	2.09	8,680	1.59	2.08
Non-interactive	6,325	1.56	1.44	8,680	1.52	1.42
New product/service objective factor	6,325	0.83	0.31	8,680	0.77	0.34
Improved product/service objective factor	6,325	0.77	0.29	8,680	0.72	0.30
Process innovation objective factor	6,325	0.75	0.33	8,680	0.64	0.37
Control variables						
Employment	6,325	231.20	551.42	8,680	443.54	3,394.39
Exporter	6,325	0.72	0.45	8,680	0.41	0.49
% of science graduates	6,325	7.43	13.52	8,680	12.50	23.13
% of other graduates	6,325	6.62	13.34	8,680	14.60	22.10
R&D	6,325	0.91	0.28	8,680	0.85	0.36

We measure the extent of firms' non-interactive knowledge search in a similar way using information from a question which asks: 'How important to your firm's innovation were each of the following data sources?' Here, we focus on four non-interactive knowledge connections: conferences, trade fairs, exhibitions; scientific journals and trade/technical publications; professional and industry associations; technical, industry or service standards. Our indicator of non-interactive knowledge search therefore takes values between 0, where the firm is not engaging in any non-interactive knowledge search activity, and 4 where it uses each non-interactive data source. On average firms were engaging with 1.5 non-interactive partnering types (Table 1). Interestingly in terms of Hypothesis 1 which suggests complementarity between interactive and non-interactive knowledge search activity we also find a weak positive correlation (0.22) between the two variables (Table 2).

The other key variable in our analysis reflects the objectives of firms' innovation activity. This is derived from a question which asks: 'How important were each of the following factors in your decision to innovate in goods or services and/or process(es)?'.Nine alternative objectives for engaging in innovation are distinguished in the UK Innovation Survey (Table 3): we associate each of these with one of the three broad innovation objectives which are the foci of our hypotheses (i.e. new products/services; improved products/services; process innovation). Innovation objectives related to new products/services we associate with firms' aims to increase their range of goods or services and/or increasing market share. The objectives of improving the quality of goods and services, increasing value added, improving health and safety and meeting regulatory requirements we associate with improved products or services with the potential both to attract new customers and add value for existing customers. And objectives associated with improving flexibility, capacity and reducing costs we associate with process innovation. In each case the measure of the broader objective is obtained creating a factor from the underlying elements. The suitability of the groupings created and their

internal consistency is demonstrated by the relatively high Cronbach's Alpha scores for each factor (Table 3).

Table 2: Correlation Matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Interactive	-									
(2) Non-interactive	0.2218	-								
(3) New product/service objectives factor	0.0757	0.1944	-							
(4) Improved product/service objective factor	0.1544	0.2881	0.3779	-						
(5) Process innovation objective factor	0.0867	0.2020	0.2983	0.5499	-					
(6) Employment	0.0373	0.0174	0.0120	0.0284	0.0241	-				
(7) Exporter	0.1234	0.1038	0.1418	0.0209	0.0486	0.0100	-			
(8) % of science graduates	0.1528	0.1426	0.0456	-0.0089	-0.0414	-0.0174	0.2120	-		
(9) % of other graduates	0.0331	0.0728	0.0395	-0.0038	-0.0001	0.0041	0.0296	0.1236	-	
(10) R&D	0.0549	0.0803	0.0950	0.0873	0.0783	-0.0421	0.0969	0.0798	0.0356	-

Table 3: Grouping of Innovative Objectives

Innovation Objectives	Factor	Cronbach's Alpha
Increasing range of goods or service	New products/services	0.7518
Increasing market share		
Improving quality of goods or services	Improved products/services	0.8476
Improving health and safety		
Meeting regulatory requirement		
Increasing value added		
Improving flexibility for producing goods or	Process innovation	0.803
Improving capacity for producing goods or services		
Reducing costs per unit produced or provided		

We also include in our analysis five variables which previous studies have linked to dimensions of innovation activity. First, we include a binary indicator of whether or not a firm has an in-house R&D capability (Love and Roper, 2001, Love and Roper, 2005, Griffith et al., 2003). In our sample of innovating plants an average of 88 per cent of firms had an R&D capability, something which varied relatively little between firm sizebands or sectors. Second, we include two variables reflecting the strength of firms' human capital – the percentage of the workforce which are science graduates and the percentage holding other graduate level qualifications (Leiponen, 2005, Freel, 2005, Hewitt-Dundas, 2006). On average, 10.2 per cent of firms' workforce are science graduates with a slightly larger proportion (11.0 per cent) having other graduate level qualifications (Table 1). These proportions differed relatively little between firm sizebands but more substantially by sector, with lower proportions of graduates in manufacturing (Table 1). Third, we include employment in the estimated models to reflect the scale of plants' resources. Finally, to capture any market scale effects we include a binary variable indicating whether or not a firm was selling in export markets. Previous studies have linked exporting

and innovative activity through both competition and learning effects (Love and Roper 2013).

Our estimation strategy follows previous studies which have considered the determinants of the extent of firms' interactive connections (Moon 2011). As the dependent variables both in the models for the extent of firms interactive and non-interactive connections are count variables either Poisson or Negative Binomial models are appropriate. However, in both cases a relatively large proportion of innovating firms have no external connections and so we also consider the zero inflated Poisson (ZIP) and zero inflated negative binomial models (ZINB)[8]. Vuong tests consistently suggest the superiority of the ZIP and ZINB models and both are reported here[9]. Our estimation sample is based on pooled data from four waves of the UK innovation survey, an approach we adopt to allow robust sub-sample estimates. To allow for sectoral and temporal heterogeneity we also include sector dummies at the 2-digit level and wave dummies in each model (not reported).

4. ESTIMATION RESULTS

We divide the presentation of results into three main sections. First, we report baseline models for the whole group of innovating firms relating interactive and non-interactive connections to their innovation objectives. Second, as previous studies have suggested potential differences in the determinants of firms' interactive connections by sector (Moon 2011), and the differential value of external connections for firms of different sizes (Vahter, Love, and Roper 2013), we report sub-sample estimates for specific groups of firms by industry and sizeband. These sub-sample estimates also provide a robustness check on the full sample estimates.

[8] For our whole sample of innovating firms 52 per cent of firms have no interactive relationships while 37 have no non-interactive relationships.
[9] Estimation of either Poisson or negative binomial models suggest almost identical results to those presented here.

4.1 Whole sample estimates

Baseline models of firms' interactive and non-interactive connections for the whole group of innovating firms are reported in Table 4. Our first hypothesis relates to the potential for a complementary connection between interactive and non-interactive connections in firms' knowledge acquisition strategies[10]. Positive and strongly significant coefficients on the number of interactive and non-interactive connections in both models provide strong support for this hypothesis, a result which proves robust across different estimation approaches. The implication is that firms with interactive connections as part of their knowledge acquisition strategy are also more likely to have non-interactive connections and vice versa. As indicated above, this complementarity may arise either from the different types of learning processes - exploratory and exploitative – implicit in interactive and non-interactive connections, and/or from economies of scope as firms learn how to better manage and co-ordinate their external connections (Love, Roper, and Vahter 2014).

Our remaining hypotheses focus on the connections between firms' innovation objectives and their knowledge acquisition strategies. Hypothesis 2 argues that interactive connections, which facilitate exploratory learning processes, will be most strongly related to innovation strategies which emphasise the introduction of new rather than improved or upgraded products. The evidence from our baseline models, however, provides no support for this view with innovation objectives related to new product or service introductions linked only to non-interactive connections, while improved products and services are strongly linked to both interactive and non-interactive forms of search (Table 4). One possibility is that this reflects a weakness in our survey data which identifies a range of innovation objectives focussed specifically on the introduction of new products/services and processes and excludes less blue sky activity. In terms of standard definitions of different types of R&D activity this range of

[10] We have little insight from previous studies about any complementary relationship between firms' interactive and non-interactive relationships. There is some evidence however of complementarities between specific types of interactive relationships (Roper, Du, and Love 2008).

activities is in the 'applied' or 'experimental development' rather than 'basic' domains, and it may be that interactive, more exploratory learning processes are more strongly linked to basic research[11]. Whatever the explanation, our baseline models provide no support for Hypothesis 2.

Table 4: Interactive and non-interactive search: Baseline models for whole sample

	Interactive		Non-interactive	
VARIABLES	Zero inflated Poisson	Zero inflated negative binomial	Zero inflated Poisson	Zero inflated negative binomial
Non-interactive	0.101***	0.104***		
	(0.00963)	(0.00980)		
Interactive			0.0405***	0.0405***
			(0.00548)	(0.00548)
New product/service objective factor	-0.0441	-0.0389	0.103**	0.103**
	(0.0445)	(0.0464)	(0.0408)	(0.0408)
Improved product/service objective factor	0.266***	0.301***	0.546***	0.546***
	(0.0665)	(0.0699)	(0.0567)	(0.0567)
Process innovation objective factor	0.121***	0.126***	0.157***	0.157***
	(0.0431)	(0.0447)	(0.0384)	(0.0384)
Log(employment)	0.00481	0.00591	0.0367***	0.0367***
	(0.00820)	(0.00839)	(0.00746)	(0.00746)
Exporter	0.00948	0.00908	-0.0378	-0.0378
	(0.0314)	(0.0324)	(0.0267)	(0.0267)
% of science graduates	0.00228***	0.00243***	0.00227***	0.00227***
	(0.000592)	(0.000617)	(0.000548)	(0.000548)
% of other graduates	0.00153**	0.00163**	0.00205***	0.00205***
	(0.000674)	(0.000700)	(0.000537)	(0.000537)
R&D spending dummy	-0.0457	-0.0436	-0.0431	-0.0431
	(0.0512)	(0.0539)	(0.0399)	(0.0399)
Constant	1.044***	0.978***	-0.125	-0.125
	(0.258)	(0.272)	(0.251)	(0.251)
Vuong test (Z value)	53.20***	44.35***	20.01***	158.33***
LR test for over dispersion of variance		63.77***		0.00013
Observations	15,866	15,866	15,866	15,866
Degree of Freedom	15,774	15,774	15,774	15,774

Note: coefficients reported. Robust standard errors in parentheses control for possible cluster of reporting units belonging to the same enterprise (***p<0.01, **p<0.05, *p<0.1)

[11] The OECD Frascati manual defines the types of R&D activity as follows: Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts without any particular application or use in view; Applied research is also original investigation undertaken in order to acquire new knowledge. It is however, directed primarily towards a specific practical aim or objective; Experimental development is systematic work … that is directed to producing new materials products and devices; to installing new processes, systems and services; or to improving substantially those already produced or installed (OECD 2002)

Hypothesis 3 suggests that where firms' innovation objectives relates to product or service improvements, non-interactive connections will be more common. In our baseline models the equation coefficients provide some support for Hypothesis 3. Although both interactive and non-interactive variables have significant coefficients, the latter are much larger than the former, suggesting the stronger association of non-interactive knowledge sources (Table 4).

Our final hypothesis argues that process innovation objectives are likely to be most strongly related to non-interactive connections as firms seek to make incremental changes to established processes on the basis of external knowledge embodied in either consultants or suppliers or codified into technical guidelines or manuals (Robertson, Casali, and Jacobson 2012). There is little support for this hypothesis: Both interactive and non-interactive search processes have positive and significant coefficients for the process innovation factor, with coefficients of almost equal size.

To summarise, for all firms we find strong positive complementarity between firms' interactive and non-interactive connections. We also find tentative evidence that non-interactive connections are linked most strongly to innovation strategies oriented towards incremental product/service change and (to a lesser extent) process improvement. Perhaps more surprisingly, we find that there is no association between interactive linkages and innovation strategies geared towards the introduction of new products and services. In terms of the control variables, the most consistent effects relate to the share of firms' workforces which are graduates – the more graduate employees the firm has the greater the likelihood of having both interactive and non-interactive connections (Table 4). This is consistent with an absorptive capacity argument and the idea that firms with higher levels of human capital may be better able to absorb external knowledge (Robertson, Casali, and Jacobson 2012). Interestingly, in the context of previous discussion of firm size and external connections (van de Vrande et al. 2009; Vahter, Love, and Roper 2013) we find no significant relationship between the number of interactive connections and

firm size although larger firms are more likely to have more non-interactive connections.

4.2 Sub-sample estimates

Previous studies have suggested differences in the scope and focus of the innovation strategies of smaller and larger firms (Acs and Audretsch 1990), and between firms in services and manufacturing industries (Suh and Kim 2012; Tether 2005; Howells and Tether 2004). Previous studies have also emphasised the rather different partnering behaviour of small firms in innovation (van de Vrande et al. 2009), and the differential benefits which firms of different sizes may derive from having external innovation connections (Vahter, Love, and Roper 2013). Sectoral differences in organisational factors and appropriability regimes may also influence firms' external innovation connections (Moon 2011). Both suggest the potential value of considering possible sizeband and sectoral contrasts in the link between firms' innovation objectives and their approach to developing external innovation connections.

Table 5 links firms' innovation objectives to the extent of their interactive and non-interactive connection for small firms (with 0-49 employees), medium (50-249 employees) and larger firms (250 plus employees). Three points stand out. First, our general finding of the complementarity of interactive and non-interactive connections proves robust for firms in each sizeband. Second, we are again unable to find any support for the notion that innovation objectives linked to the development of new products/services will be related more strongly to interactive connections: indeed the lack of significance here is clear across all three sizebands. Third, and also consistent with our general findings, there is only tentative evidence that non-interactive linkages are more strongly associated with innovation objectives related to product or service improvement. In terms of innovation objectives related to process change there is, however, some difference across the sizebands. In the case of large firms Hypothesis 4 is now confirmed: process change is associated only with non-interactive knowledge search. Interestingly, the reverse is true for small firms (less

than 50 employees), where only process change is associated only with interactive connections. Medium-sized firms display an intermediate pattern.

Table 5: Interactive and non-interactive search: Sizeband

	Interactive			Non-interactive		
VARIABLES	Small	Medium	Large	Small	Medium	Large
Non-interactive	0.104***	0.0873***	0.0729***			
	(0.0125)	(0.0131)	(0.00959)			
Interactive				0.0848	0.0303***	0.0267***
				(0.0531)	(0.00730)	(0.00497)
New product/service objective factor	-0.0732	0.0786	0.0267	0.522***	0.174**	0.212***
	(0.0560)	(0.0705)	(0.0448)	(0.0733)	(0.0686)	(0.0562)
Improved product/service objective factor	0.249***	0.316***	0.302***	0.175***	0.610***	0.482***
	(0.0845)	(0.0845)	(0.0631)	(0.0498)	(0.0971)	(0.0682)
Process innovation objective factor	0.134**	0.123**	0.0303	0.0360	0.114*	0.196***
	(0.0534)	(0.0589)	(0.0437)	(0.0312)	(0.0613)	(0.0496)
Log(employment)	-0.0677*	0.0309	0.0630***	-0.0650*	0.0270	0.0245
	(0.0364)	(0.0352)	(0.0155)	(0.0354)	(0.0369)	(0.0162)
Exporter	-0.00355	0.0667	0.0517	0.00244***	0.0176	0.0917***
	(0.0395)	(0.0443)	(0.0336)	(0.000673)	(0.0431)	(0.0333)
% of science graduates	0.00224***	0.00157	0.00448***	0.00183**	0.00114	0.00298***
	(0.000707)	(0.00108)	(0.000688)	(0.000724)	(0.000956)	(0.000768)
% of other graduates	0.00124	0.00237**	0.000232	-0.0637	0.00326***	0.000927
	(0.000823)	(0.000964)	(0.000777)	(0.0519)	(0.000735)	(0.000632)
R&D spending dummy	-0.0683	0.0655	0.102**	0.0848	0.000765	0.00706
	(0.0632)	(0.0749)	(0.0462)	(0.0531)	(0.0669)	(0.0418)
Constant	1.054***	0.446	0.522	-0.0977	0.0485	-0.0896
	(0.374)	(0.336)	(0.419)	(0.276)	(0.258)	(0.318)
Vuong test (Z value)	33.65***	26.81***	31.04***	14.38***	9.85***	11.07***
Observations	7,272	4,431	4,163	7,272	4,431	4,163
Degree of Freedom	7,180	4,339	4,071	7,180	4,339	4,071

Note: coefficients reported. Robust standard errors in parentheses control for possible cluster of reporting units belonging to the same enterprise (***p<0.01, **p<0.05, *p<0.1)

Estimating sectoral sub-samples for manufacturing and services suggests broadly similar results (Table 6). Strong complementarity is evident between interactive and non-interactive connections for both manufacturing and services firms. As elsewhere we find little evidence of any relationship between interactive connections and new innovation, with some support for

a strong link between innovation objectives related to improved product/services and non-interactive connections. Indeed, perhaps the most interesting finding is the similarity of results for manufacturing and services, in terms of both the pattern of significance and coefficient size.

Table 6: Interactive and non-interactive search: Manufacturing and Services

	Manufacturing		Services	
VARIABLES	Interactive	Non-interactive	Interactive	Non-interactive
Non-interactive	0.0967***		0.0947***	
	(0.0119)		(0.0131)	
Interactive		0.0478***		0.0434***
		(0.00738)		(0.00804)
New product/service objective factor	0.0869	0.409***	-0.0907	0.199***
	(0.0709)	(0.0645)	(0.0569)	(0.0524)
Improved product/service objective factor	0.224***	0.865***	0.281***	0.848***
	(0.0810)	(0.0719)	(0.0891)	(0.0695)
Process innovation objective factor	0.104*	0.163***	0.138**	0.102**
	(0.0532)	(0.0524)	(0.0562)	(0.0454)
Log(employment)	0.0455***	0.0680***	-0.0144	0.0176*
	(0.0114)	(0.0115)	(0.0113)	(0.0101)
Exporter	-0.00162	-0.0565	0.0142	-0.0504
	(0.0431)	(0.0490)	(0.0402)	(0.0329)
% of science graduates	0.00438***	0.00421***	0.00178***	0.00158**
	(0.00105)	(0.000925)	(0.000688)	(0.000633)
% of other graduates	0.00362***	0.00232**	0.00117	0.00187***
	(0.00104)	(0.000927)	(0.000777)	(0.000622)
R&D spending dummy	0.0142	-0.0343	-0.0517	-0.0403
	(0.0879)	(0.0748)	(0.0609)	(0.0485)
Constant	0.295	-0.722***	0.644***	-0.330*
	(0.258)	(0.180)	(0.234)	(0.191)
Vuong test (Z value)	34.09***	11.74***	38.76***	15.33***
Observations	6,325	6,325	8,680	8,680
Degree of Freedom	6,258	6,258	8,609	8,609

Note: coefficients reported. Robust standard errors in parentheses control for possible cluster of reporting units belonging to the same enterprise (***p<0.01, **p<0.05, *p<0.1)

3. CONCLUSIONS AND DISCUSSION

Firms can acquire the knowledge necessary to drive innovation either through internal discovery processes or through external search (Chesbrough 2007; Chesborough 2006). Here, using data on a large sample of UK companies, we examine the factors which determine two different modes of knowledge acquisition activity: interactive connections which may be exploratory in character and in which there is a mutuality to learning, and non-interactive connections in which knowledge flows from one party to another and learning is therefore one-sided (Glückler 2013).

In terms of our hypotheses two main empirical results stand out. First, we find strong and consistent support for complementarity between non-interactive and interactive connections across firms in all sectors and sizebands. In other words, firms which have more interactive connections as part of their innovation activity also have more non-interactive connections. On the basis of our survey data we are, however, unable to distinguish whether this complementarity is due to differences in the functional content of these connections (Faems et al. 2010; Lavie and Rosenkopf 2006), economies of scope in their management and coordination (Love, Roper, and Vahter 2014), or both. Second, we find some tentative evidence that where firms have innovation objectives which relate to product or service improvement they are more likely to establish non-interactive rather than interactive connections. Such connections are likely to be exploitative (rather than exploratory) focussed on the application and commercialisation of existing knowledge rather than the creation of new knowledge which might provide the basis for the introduction of new products or services. In our data, however, we are unable to find any consistent evidence for a link between innovation objectives related to new products and interactive connections.

Our analysis suggests one other consistent result. We find a consistent and positive relationship between the quality of firms' human capital and their external connections (both interactive and non-interactive). This

provides a link between our study and previous analyses which have linked firms' propensity to develop external connections to their internal capabilities – particularly absorptive capacity (Spithoven, Clarysse, and Knockaert 2011; Schmidt 2010; Xia and Roper 2008). It also suggests that one – indirect – benefit of investments or policy initiatives designed to improve firms' human capital will be an increase in inter-organisational connectivity or openness which itself has potentially positive externalities (Roper, Vahter, and Love 2013).

Our findings on the impact human capital on firms' external connections highlight the contingent nature of such activities. Sectoral factors, such as regulation, may be important but individual firm-level influences – such as skill attributes and firms' innovation objectives – also play a significant role. Such factors may also influence the value which firms' derive from their external connections and in future papers we aim to examine how firms' interactive and non-interactive connections contribute to innovation performance.

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