The relevance of internal and external sources of knowledge in the innovation performance of UK enterprises

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Abstract

The paper explores the impact of different sources of knowledge on the innovation performance of enterprises operating in the UK. Three main sources of knowledge are considered: own generation via R&D expenditure; internal transfer within the company; and acquisition via collaboration with external partners. The national and international dimensions of the internal networks and of the external collaborative agreements are explored and tested for their impact on innovation performance. The study uses information from the UK Community Innovation Surveys 3 and 2. We find that in-house R&D activities are relevant in terms of innovation performance over and above both internal networks and collaborative agreements. Thereafter, the second strongest predictors are intra-firm networks and in particular intra-firm networks that span over a number of different countries. Finally, our data suggest that collaborative agreements increase continuous improvements of products, and are, to a much lesser extent, associated with new-to-market innovations compared with in-house R&D and intra-firm networks.

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Keywords: Source of knowledge; knowledge transfer; networks and innovation; R&D; collaborative agreements; innovation; internationalization; Community Innovation Survey UK.

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1. Introduction

The last few decades have seen a large number of studies on issues of knowledge and innovation from a strictly economics perspective as well as from others, particularly sociology of organization and management. On the economics side the interest is usually connected with issues of competitive advantages of firms and/or the comparative advantages of countries. The conclusion regarding the impact on the performance of companies involves studies and/or assumptions related to a variety of elements including the following: (a) acquisition of knowledge; (b) translation of acquired knowledge into innovation of products and/or processes; and (c) how and to what extent product and/or process innovation result in improved performance of the company and country.

Each of these elements in itself generates a variety of studies according to assumptions, context – such as industry and/or country – and the specifics of knowledge or innovation or performance one wants to analyse. This paper is concerned with (a) the acquisition of knowledge and related development of innovation and with (b/c) how the acquisition of knowledge translates into innovation performance. The context of the study is the UK and the empirical information derives from the Community Innovation Survey on which more in Section Four.

Many studies have concentrated on the acquisition of knowledge through knowledge transfer. The transfer may take place internally to the firm that is between different units of the same company or between the external environment and a

specific unit of the company and via the latter to other parts of the company through internal transfers. The external environment may encompass competitors, customers, suppliers or distributors. It may also encompass the wider macro environment through elements that contribute to the regional or national systems of innovation such as skills and education levels, proximity to universities and their research bases or public expenditure for R&D. The geographic context – be it region or country or the international context – is of relevance for both the generation and the transfer of knowledge.

The extent to which transfer of knowledge takes place in whichever context depends on a variety of elements which will be considered in the next section. Nonetheless, transfer is only one of the sources of knowledge and innovation acquisition. The other main source is the direct generation of knowledge and innovation by the unit under consideration. The aim of our study is to assess the extent to which these three sources of knowledge – own generation, acquisition from sources internal to the company (i.e., via the company's internal networks) and acquisition via external networks – specifically via collaborative agreements - translate into innovation performance for the single enterprise.

The paper proceeds as follows. The next section discusses various types of sources of knowledge and their relationship to innovation; in Section Three we set out our hypotheses and analyse some specific issues related to them. Section Four discusses data and methods. Section Five presents the results and the final section concludes.

2. The acquisition of knowledge: own generation and transfer

The specific context and data source of our study is the Community Innovation Survey and this means that our unit of study is the single enterprise which can be related to a single unit firm or be part of a firm comprising several units/enterprises. In the latter case all the units may be located in a single country or spread in several countries as in the case of units which are part of a transnational corporation (TNC). This specific context sets the scene for our analysis of sources of knowledge which we take to be the basis and precondition for innovation.

For any given enterprise there are two main sources[1] for the acquisition of knowledge and related development of innovation: (a) own generation and (b) transfer from other sources. They are interrelated in two ways: first, because any knowledge and innovation acquired from other sources may lead to further generation of knowledge and innovation by the recipient enterprise; second, because an enterprise that is active on the generation side will be sought after as a desirable partners for a two way transfer.

The main strategy for own generation (a) is to engage in research and development activities; thus R&D expenditure and general issue of R&D laboratories, including their location (Patel and Pavitt, 1994; Pearce and Papanastasiou, 1999) has been a classic variable in the explanation of innovation performance. Own generation may be a 'solo' activity or a joint venture between two or more partners. Enterprises may also source knowledge through engaging in cooperative agreements with other firms as well as with a variety of institutions such as universities and public research institutes. There is, in fact, evidence of a rapid growth in R&D alliances over the last

[1] The CIS contains questions related to the enterprise's source of information about innovation. We do not consider these to be equivalent to what we here describe as sources of knowledge and innovation. Information about innovation is not the same as acquisition of knowledge or development of innovation themselves.

two decades (Hagedoorn, 1996). These agreements, too, may be at the national or international level. Indeed, the growth in the number and importance of TNCs over the last few decades took place in tandem with considerable growth in cross-border cooperation agreements, with much of the latter taking the form of R&D alliances (Hagedoorn, 2002, Hegert and Morris, 1988, Narula, 2000 and 2003). In the case of collaborative agreements on innovation the distinction between own generation and transfer is not clear cut because the partners exchange information in the process of generating new knowledge.

Acquisition from outside the enterprise (b) implies transfer of knowledge and two main sources are usually considered. Internal transfers within the company whenever the enterprise belongs to a network company; and external transfers from channels outside the ownership structure of the company to which the enterprise belongs.

However, whatever the specific sources, a relevant issue to confront in discussing acquisition of knowledge from other units – whether internal or external to the company to which our enterprise belongs - is transferability. Transferability has been associated and studied in relation to the following. First, the characteristics of knowledge itself whether it is tacit or codifiable (Polanyi, 1966, 1967). Second, the characteristics of the recipient enterprise, for example how congenial and developed its absorptive capacity is (Cohen and Levinthal, 1989, 1990). Third, the degree of embeddedness of the enterprise in the locality which may affect the transferability of knowledge from and to it by other company's units or from the external environment. Moreover, embeddedness can be seen as a two dimensions characteristic; Forsgren *et al.* (2005) see embeddedness as a characteristic with a double dimension related to the degree to which the unit is embedded in the external environment and location and to

which it is embedded in the internal company network: in this perspective both the business and external contexts are crucial to the transferability issue. Fourth, the suitability of different sources of knowledge for transfer (Foss and Pedersen, 2002).

Fifth, the relationship between the different units potentially or actually involved in the transfer. On this last issue several strands of research are important. One strand emphasises the relationship between headquarters of the company and its subsidiaries. The organizational side of the company and the degree of decentralization are relevant elements in the transfer of knowledge and innovation (Bartlett and Goshal, 1989; Gupta and Govindarajan, 1991 and 2000; Hedlund, 1986; Hedlund and Rolander, 1990; Zanfei, 2000). If the subsidiary has considerable freedom to interact with the local environment, it may be in a better position to exploit and absorb local knowledge. In this respect the internal organizational structure of the company's network becomes relevant for the acquisition and spread of knowledge[2]. We might expect headquarters to be more prone to acquisition of knowledge from the environment since they are less hampered by control decision mechanisms (Castellani and Zanfei, 2006). A second strand highlights the nature of the activities of the units potentially or actually involved in the transfer and specifically whether the activities are substitutes or complementary (Forsgren, 2006);

Sixth, the geographical context of the transfer: whether the units between which the transfer could or does take place are located within the same region or country or across frontiers (Frenz and Ietto-Gillies, 2007). As regards the internal network the company's subsidiaries may spread within a single country; however, in the case of transnational companies, they spread across a number of countries[3]. A

[2] It becomes also relevant for the degree to which knowledge and innovation spillover from the firm to the local environment (Zanfei, 2000).
[3] With respect to new venture firms, Zahra *et al* (2000) found that international diversity as well as entry mode impact on technological learning and on performance.

company with an international internal network has scope for tapping into the knowledge of more diverse environments, on the assumption that different countries offer indeed more diverse knowledge environments than different locations within the same country. This has two consequences for the generation and spread of knowledge. First, the company as a whole has a greater learning opportunity via the operations of its subsidiaries in various countries. For example, in Cantwell's theory of international activities the TNC is viewed as a strategic decision-maker actively seeking to invest in locations which are conducive to innovation (Cantwell, 1989, 1997, 1999a, 1999b). Second, as knowledge is spread and absorbed within the company via its internal network, each subsidiary has the potential to benefit. Furthermore, the spillover effects from the subsidiaries into the various different environments in which they operate also lead to increased knowledge and innovation opportunities for the various localities in which the company operates (Cantwell, 1989; Castellani and Zanfei, 2004 and 2006). This view of TNCs and their location strategies suggests that strong local economies are likely to attract investment from TNCs (Cantwell and Iammarino, 2000, Cantwell and Piscitello, 2005, Phelps, Mackinnon, Stone and Braidford, 2003) and inward FDI may indeed be motivated by the desire to reap benefits from the innovation environment in the host country (Driffield and Love, 2003).

There is a strong interaction with regard to knowledge acquisition between internal channels of transfer and locations. Those firms that operate within a network structure which spreads over several locations have opportunities for learning from a variety of different locations. A company's internal network then acts as a facilitator for the spread of knowledge from subsidiary to subsidiary and from location to location. The extent to which the various locations act as learning opportunities partly

depends on how varied they are, how knowledge intensive they are and whether the knowledge they embody is specific and relevant to the firm's activities.

3. Hypotheses and related discussion

On the basis of the processes of knowledge acquisition sketched in the previous section we derive at the following hypotheses. Firstly, we consider the effects of enterprise internal sources of knowledge on innovation performance.

H1 *Enterprises that engage in own development of knowledge and innovation via R&D expenditure are likely to show a higher innovation performance compared to other enterprises.*

Secondly, there are two hypotheses related to the acquisition of knowledge through internal channels of transfer and location.

H2a *Enterprises that are part of companies that operate within internal networks are more likely to be innovative than enterprises that are part of an independent, single-unit firm on the assumption that there is exchange of knowledge between units of the same company.*[4]

The second hypothesis 2b related to company internal networks addresses the location of the company internal networks. We expect that extensive international internal networks have a higher impact on innovation performance compared with national only networks, because they enable access to a diverse range of knowledge (Frenz et al. 2005; Frenz and Ietto-Gillies, 2007).

[4] The assumption that there is exchange of knowledge between units of the same company does not mean acceptance that companies and TNCs in particular are highly efficient channels for the internal spread of knowledge (Kogut and Zander, 1993). Though we tend to accept Forsgren's (2006) critique of Kogut and Zander's approach, nonetheless we assume that some knowledge exchange takes place between units of the same company.

H2b *Enterprises that are part of an internal network that operates in several countries, and, therefore, are part of a transnational company, are more likely to show high innovation performance compared to enterprises which belong to companies operating in a single country, in our case the UK.*

Our third set of hypotheses relates to the impact of external transfers of knowledge through channels outside the ownership structure of the company to which the enterprise may belong. Enterprises can acquire knowledge via cooperative agreements with other private firms or with public institutions and universities. We expect a positive impact on performance. As mentioned in section two we see this third source as intermediate between own generation via R&D[5] and transfer via internal networks.

H3a *Cooperative agreements with external institutions increase the potential for knowledge acquisition and innovation.*

H3b *Cooperative agreements with external institutions in different countries may further increase the potential for knowledge acquisition because they may allow the enterprise to access the diverse knowledge of the different countries and innovation systems.*

Our single country study does not give scope for comparative analyses of different macro environments such as different national systems of innovation. However, macro elements may have different effect according to sectors and this is one of the reasons why we include 'sectors' in the control variables.

Some issues arise which have a bearing on the interpretation of the results. First the extent to which the *three sources* are related that is whether and to what extent the three sources are *complementary* or *substitutes* in terms of innovation

[5] Some R&D expenditure may indeed go towards funding collaborative ventures on innovation. We have no way of separating the expenditure directed to solo activities from that directed to collaborative activities.

development. Is the enterprise with substantial R&D expenditure and, therefore, with substantial own source of innovation more or less likely to engage in innovation development via collaborative agreements or via internal transfers? There is no *a priori* conclusion: it could be that reliance on own sources leads to a lower level of activity to secure acquisition via collaboration or via internal transfers. However, it could also be that innovation active enterprises are active at all levels and with regard to all sources; moreover, a research strong enterprise may attract attention from internal or external units willing to engage in knowledge development and transfers.

Similarly, is an enterprise which is part of an internal network more or less likely to seek external innovation cooperation? And is an enterprise with access to an international internal network – because it is part of a TNC – more or less likely to seek international external innovation linkages?

Again these questions cannot be answered *a priori*. It may be argued that the existence of internal networks gives the enterprise an opportunity to engage in external collaborations and, therefore, that the two types of linkages – internal and external – develop as complements within either the national or international dimension. On the other hand, it may be argued that an enterprise that has access to knowledge in other locations – be they within the national territory or international – has less need to seek costly and risky external cooperative agreements; therefore, in this perspective, the relationship will be seen as one of substitution. Both cases are plausible and it may be that in reality the relationship is, partly, sector-specific. For example, in research intensive sectors where innovation-specific cooperative agreements are very risky in terms of knowledge spillovers away from the enterprise the trend might be more towards the establishment of internal channels of knowledge acquisition rather than external ones.

If the relationship between internal networks and external collaborations is one of substitution we would expect enterprises that are part of wide internal networks to be less likely to engage in external agreements; vice versa in the case of a complementary relationship. However, once the enterprise is involved in all three types of networks, we would expect all of them to contribute to innovation performance and an enterprise that has access to more than one type of source to exhibit a higher innovation performance compared with an enterprise that has access to one type of source only. Ex ante the enterprise may decide whether it would make sense in terms of its innovation strategy to engage in innovation-specific external agreements; however, ex post one would expect positive innovation outcomes from the strategy. We shall present correlation coefficients to throw some light on the complementarity versus substitution relationship between the sources of knowledge and innovation.

The second issue we want to discuss relates to the nature of our information in relation to the hypotheses. First, we should note that our study and our performance indicators relate to innovation; yet many of the points made above refer to knowledge. There is clearly a relationship between knowledge and innovation; the latter would not be possible without the former. Thus knowledge development is essential for innovation. However, not all knowledge leads to innovation; unless the business, social and economic conditions are congenial, we may have development of knowledge without corresponding development in innovation let alone improved performance linked to innovation.

Second, it must also be noted that the role and position of internal and external linkages are not symmetrical. Strategically, the internal networks are developed by the company with a variety of objectives in mind ranging from location of the whole or

parts of the production process to the development of markets, to the search for assets or resources. Knowledge acquisition and innovation may play a role but not in all cases, and, even where it does, it is unlikely to be the main one. If the variable related to internal networks were to show low or no effect on innovation performance this could be due to a variety of reasons and specifically: (a) there is indeed low level of knowledge transfer within the company – contrary to the evolutionary theory's conclusions. There may be many reasons for this; the strategies of the company's HQs or the enterprise itself or the internal organization of the company does not facilitate knowledge transfer; and (b) our variable – on which more in the next section - does not fully capture the full relationship between the company's units.

In the case of external collaborations the reverse of the latter statement is true, particularly, because in the case of the CIS database which we are going to use, the specific variable we use refers to cooperation agreements with the aim of developing and sharing innovations.

4. Data and methods

4.1 The Community Innovation Survey

The data used derives from the second and third Community Innovation Surveys (CIS). The Department of Trade and Industry conducted CIS3 in 2001 and CIS2 in 1997. Among the innovation surveys readily available in the UK (and for that matter in the EU) the Community Innovation Survey is perhaps the most comprehensive database; comprehensive in terms of the enterprises surveyed – the CIS covers all manufacturing sectors and most private services (sections C to K of the UK standard industrial classification of economic activities) as well as small (10 or more employees) and large enterprises, in terms of the range of questionnaire items

including direct measures of innovation activity and a wide variety of factors influencing innovation.

Questions asked in CIS relate to input and output measures of innovation as well as cooperation on innovation. Information on structural characteristics is also provided, in particular enterprise size, in terms of turnover and employment figures. In addition to the questionnaire data, the CIS include information from the Inter-Departmental Business Register. The latter gives information on structural features of the surveyed enterprises as well as whether the respondent is part of a wider company group or whether the enterprise is independent.

This paper is based on the overlap between CIS3 and CIS2; it relates to all those enterprises that answered both CIS3 and CIS2. This choice was guided by two aims: first, to include among the variables of innovation performance the extent of sustainability and continuity of innovation; for this we needed a dynamic perspective on innovation performance; and second, to allow for a time-lag between input and output variables. In total 786 enterprises answered both CIS3 and CIS2.

With respect to the internal company network at the international level, the CIS does not contain the relevant information; in order to access it we use Dun and Bradstreet's 'Who owns Whom' (WoW), a large database that gives company tree data in the form of name, number and location of subsidiaries.[6] The CIS enterprises were matched with the company tree data on WoW for the year 2000. The resulting dataset used in this paper contains 679 observations; 257 enterprises are part of a TNC, out of which 137 are of foreign origin. Among the remaining 422 enterprises not part of a TNC – and therefore uninational firms – are 159 which belong to a UK

[6] WoW defines subsidiaries by a 50 percent or more ownership. This constraint prevents us from including among the TNCs all those with associates abroad i.e. with ownership stakes of 10 to 50 percent. The sample of TNCs is, therefore, underestimated. Nonetheless the problem may be partly compensated by the fact that the data on WoW are biased towards reporting TNCs rather than smaller UNCs.

uninational company group and 263 enterprises which are independent enterprises. Due to missing values affecting some of the CIS variables the final regression analysis is based on 679 observations.[7]

The set of 679 CIS enterprises analysed in this paper differ from the distribution of the whole population in the following: there is a bias towards large enterprises (50 employees or more) and towards manufacturing. Low technology intensive private services are under-represented and public services are not included in the survey.

4.2 Dependent variables

Innovation performance is a multidimensional concept and is represented by several indicators taken from the CIS3, as well as from the link between CIS3 and CIS2. In particular we use variables related to product-type innovations and the share of turnover derived from product innovations.

The first variable used to measure innovation performance is called PRODUCT INNOVATION. Enterprises were asked whether or not they introduced any new products (goods and services) which were new to the enterprise during the three year period 1998 to 2000. The resulting variable is a binary variable, coded as zero if the enterprises did not introduce a new product and coded as one if they introduced a new product. The second variable is called NOVEL PRODUCT INNOVATION. If enterprises answered yes to the question related to product innovation, it was further asked

[7] There are 786 enterprises in the CIS overlap, i.e. enterprises that answered both CIS3 and CIS2. 478 of these are included in the WoW database. All 478 enterprises included in WoW are enterprises that belong to a wider company group. Of the remaining 308 firms, which could not be matched with WoW, 201 were independent entities, according to the CIS variable on group belonging. In 107 of the 786 observations common to CIS3 and CIS2 all the information available is that the enterprises belong to a company group. It is not known whether the relevant company-group is uni- or multinational; nor is anything about their degree of multinationality known. For this reason those 107 observations have been dropped from the analysis.

whether or not the new product was not only new to the enterprise, but also new to the enterprise's market. The next variable is designed to capture whether innovation is long term and sustained or a more temporary phenomenon. To capture product-type innovation we construct a variable called SUSTAINED PRODUCT INNOVATION which takes a value of one if the enterprise engaged in product innovation in both CIS2 and CIS3 and zero otherwise, i.e. the enterprises had a new product in either CIS2 or CIS3 or in neither survey periods[8].

The second set of variables measures the share of turnover from product innovations. The variable TURNOVER IMPROVED PRODUCTS measures the percentage of turnover in the year 2000 which an enterprise generated through significantly improved products. The variable TURNOVER FROM NEW PRODUCTS is the share of turnover which derived from new products, and finally TURNOVER FROM NOVEL PRODUCTS is the percentage of turnover from new-to-market products.

4.3 Independent variables

In order to test our first hypothesis which states that firms generate innovations through internal R&D sources we use a variable that captures whether or not an enterprise had expenditures related to intramural R&D over a prolonged period of time; i.e. the enterprise declared to have carried out intramural R&D in both CIS2 and 3. We therefore distinguish enterprises that continuously commit to in-house R&D from those which may carry out R&D on a one-off basis or in relation to a single project. This variable is called R&D.

The next set of independent variables refers to characteristics of the wider company-internal network. To test hypothesis 2a, which states that access to an

[8] The persistence of innovative activities has been studied in Cefis (2003) and Cefis and Orsenigo (2001). Frenz and Ietto-Gillies (2007) assess the impact of multinationality on it.

internal network irrespectively of where it is located is positively associated with innovation performance, we use a variable called INTERNAL NETWORK. This variable is a binary variable coded 1 if an enterprise was part of a wider company internal network and is coded 0 otherwise.

To test hypothesis 2b we use a variable called INTERNATIONAL INTERNAL NETWORK. This variable is coded 1 when an enterprise is part of an internal network that spans over two or more countries, i.e. the enterprise is part of a TNC and is coded 0 if the enterprises not part of a TNC, i.e. if the enterprise is part of a group operating in the UK only or if the enterprise is independent. Thus, the variable INTERNATIONAL INTERNAL NETWORKS is a subset of the variable INTERNAL NETWORK.

In relation to our third set of hypotheses, which deals with the effects of innovation-specific external networks as a source of innovation inputs, we use two variables measuring cooperation on innovation derived from CIS2 data, thus allowing for a time-lag between cooperation activity and innovation performance. Using the time-lag has the advantage that, at least to some extent, this addresses potential issues of endogeneity between those two variables; i.e. it may be possible that increased innovation leads to increased cooperation activity. We elaborate on this point in the methods section of the paper.

The first variable, designed to examine hypothesis 3a, is called EXTERNAL NETWORK. This is a dummy variable that distinguishes between enterprises that engaged in cooperation activities on innovation with organisations which may be located inside the UK or outside the UK between 1994 and 1996 (coded 1) and enterprises that had no cooperation agreements (coded 0).

The second variable, which is designed to test hypothesis 3b, is called INTERNATIONAL EXTERNAL NETWORK. This variable selects all those enterprises that

engaged in cooperation agreements with organisations located outside the UK (coded as 1), and deselects enterprises that did not engage in cooperation with other organisations located abroad (coded as 0).

4.4 Control variables

A set of control variables is designed to capture industry environment of the enterprise and enterprise size. In the empirical analyses we control for the main effects of the INDUSTRY in which an enterprise operates. Here, we distinguish between eleven industry sectors and the relevant dummy variables are included in the regression, however, they are omitted from the presentation of results in the regression tables.[9] The variable that measures enterprise size is called ENTERPRISE SIZE and is the natural log of the number of employees.

4.5 Methods

Following some descriptive statistics summarising our dependent and independent variables we test the hypotheses developed in Section Three using single equation regression methods, more specifically probit and tobit models.

For a number of reasons our estimations are not panel estimations. This is because (i) information on internal networks is only available for one time period; (ii) there are important differences in the questionnaires of CIS2 and CIS3; and (iii) because our dependent variables are qualitative or limited dependent variables. With respect to (iii) this means that there is an incidental parameter problem in panel

[9] The eleven industry dummies are: 1. Machinery and equipment incl. transport equipment, 2. non-metallic and metal products, 3. textiles, leather, publishing, printing, 4. manufacturing not elsewhere classified incl. utilities, construction and mining, 5. other business activities incl. real estate, 6. communication equipment and scientific instruments, 7. financial, insurance, post and telecommunications, 8. wholesale, retail and trade, 9. transport services, 10. food, beverages and tobacco, 11. chemicals and pharmaceuticals.

estimations. For example, in the case of probit estimations used here, as well as in the case of alternative estimation models for binary dependent variables such as logit models, evidence suggests that for T=2 (two time periods) the bias in the maximum likelihood estimators may be as high as 100 percent (Greene, 2003, Kennedy, 2003).

There are, of course, problems related to single equation regressions which we now turn to. First, there is the problem that causality and the direction of causality can not be inferred on the basis of cross-sectional regressions. Second, and related to this, there may be issues of endogeneity. Almost all variables carry at least some degree of endogeneity, and in this paper, cooperation on innovation may be jointly determined with innovation performance.

This issue of endogeneity is, at least to some extent, addressed through the introduction of time-lags with respect to the cooperation variables which are measured using CIS2 and linked to innovation performance in CIS3.

Alternative estimation taking into account issues of endogeneity are instrument variable techniques. Instrumental variable techniques (or simultaneous equations) require that suitable instruments are found, i.e. instruments must be truly exogenous to the system and must be highly correlated with the endogenous variable, a requirement which is difficult to match and on these grounds we decided not to apply instrumental variable techniques in this paper.

Finally, a problem arises because the variable INTERNATIONAL INTERNAL NETWORKS is a subset of the variable INTERNAL NETWORKS (r=0.62) and the same holds for EXTERNAL NETWORKS (r=0.72). Because the coefficients are based on the unique contribution of each independent variable, coefficients are likely to be less significant. In order to examine this effect in more detail we first compute two models which contain just one indicator of internal and one indicator of external networks.

This is followed by a third model which contains all independent variables. The following equations are estimated to test our hypotheses**:**

Equation 1

$$Y_i = \alpha + \beta_1 R\&D + \beta_2 \textit{ INTERNAL NETWORK}_i + \beta_3 \textit{ EXTERNAL NETWORK}_i + \gamma \textit{ CONTROL VARIABLES} + \varepsilon_i$$

Equation 2

$$Y_i = \alpha + \beta_1 R\&D + \beta_2 \textit{ INTERNATIONAL INTERNAL NETWORK}_i + \beta_3 \textit{ INTERNATIONAL EXTERNAL NETWORK}_i + \gamma \textit{ CONTROL VARIABLES} + \varepsilon_i$$

Equation 3

$$Y_i = \alpha + \beta_1 R\&D + \beta_2 \textit{ INTERNAL NETWORK}_i + \beta_3 \textit{ INTERNATIONAL INTERNAL NETWORK}_i + \beta_4 \textit{ EXTERNAL NETWORK}_i + \beta_5 \textit{ INTERNATIONAL EXTERNAL NETWORK}_i + \gamma \textit{ CONTROL VARIABLES} + \varepsilon_i$$

where Y_i is a measure of innovation performance and takes on the following meanings: product innovation; novel product innovation; sustained product innovation; turnover from improved products; turnover from new products; turnover from novel products.

Probit models are estimated in the case of binary dependent variables and tobit models censored at zero in the case of the percentage of turnover from innovations. Marginal effects, the change in absolute probability of the outcome induced by the regressors dy/dx, are reported.

5. Results

Table 1 gives the results of the descriptive statistics. We also include the tolerance value for each of the independent variables in order to examine the extent of multicollinearity between them. A correlation matrix showing the zero order inter-correlations between the dependent and independent variables is in Appendix B.

Table 1 Variables and their descriptive statistics

Variables		Mean	Std. Dev.	Min.	Max.	Tolerance
Dependent variables						
1	PRODUCT INNOVATION	0.29	0.45	0.00	1.00	
2	NOVEL PRODUCT INNOVATION	0.14	0.35	0.00	1.00	
3	SUSTAINED PRODUCT INNOVATION	0.21	0.41	0.00	1.00	
4	TURNOVER FROM IMPROVED PRODUCTS	4.57	13.45	0.00	100.00	
5	TURNOVER FROM NEW PRODUCTS	3.65	11.05	0.00	100.00	
6	TURNOVER FROM NOVEL PRODUCTS	2.48	11.08	0.00	100.00	
Independent variables						
7	R&D	0.13	0.33	0.00	1.00	0.94
8	INTERNAL NETWORKS	0.61	0.49	0.00	1.00	0.50
9	INTERNATIONAL INTERNAL NETWORKS	0.38	0.49	0.00	1.00	0.58
10	EXTERNAL NETWORKS	0.27	0.44	0.00	1.00	0.46
11	INTERNATIONAL EXTERNAL NETWORKS	0.16	0.37	0.00	1.00	0.47
Control variables						
12	ENTERPRISE SIZE	4.53	1.45	2.40	9.74	0.64

Industry dummies are omitted. Number of observations is 679 with the exception of the variables Turnover from improved products, turnover from new products where the number of observations is 664. This is because 15 respondents who did not answer the relevant question were dropped.

Table 1 shows that there are 29 percent product innovators in CIS3 (T2: 1998 to 2000), 14 percent novel product innovators, 21 percent sustained product innovators in the dataset. The average share of turnover from improved products is 4.57 percent, from new products 3.65 percent and from novel products 2.48 percent.

Turning now to our independent variables, Table 1 shows that 13 percent of enterprises carried out in-house R&D between 1994 and 2000, 61 percent of enterprises are part of an internal network, i.e. these enterprises are part of a wider company group and that 38 percent of enterprises are part of an international internal network, i.e. they belong to a TNC. 27 percent of enterprises declared that they cooperated on innovation in CIS2 (T1: 1994 to 1996) and 16 percent reported that they cooperated with another organisation located outside the UK. As mentioned before, the zero-order inter-correlations between the variables internal networks and international internal networks, as well as the inter-correlations between external networks and international internal networks are above 0.60. In order to investigate this further, we computed the tolerance values which give the proportion of a

independent variables variance not accounted for by other independent variables in the model. These suggest that the individual explanatory power when estimating the full model, Equation 3, lies between 0.47 and 0.58 with respect to our independent variables capturing external sources for innovation. This in itself is not a serious problem; however, it means that the regression coefficients may under-estimate the true effects of these variables when using Equation 3.

Table 2 presents the results of the regression equation which tests the hypotheses developed in Section Three of the paper.

Table 2 Regression results

Dependent variables	HYP	PRODUCT INNOVATION			NOVEL PRODUCT INNOVATION			SUSTAINED PRODUCT INNOVATION		
Estimation model: probit		Model 1	Model *2*	Model 3	Model 1	Model *2*	Model 3	Model 1	Model *2*	Model 3
Independent variables		*M.E.*	*M.E.*	*M.E.*	*M.E.*	*M.E.*	*M.E.*	*M.E.*	*M.E.*	*M.E.*
R&D	H1	0.39***	0.39***	0.39***	0.25***	0.24***	0.24***	0.38***	0.39***	0.378***
		(6.28)	(6.30)	(6.21)	(5.51)	(5.52)	(5.40)	(0.83)	(7.08)	(6.80)
INTERNAL NETWORK	H2a	0.11**		0.06	0.04		0.01	0.03		0.01
		(2.34)		(1.15)	(1.34)		(0.24)	(0.83)		(0.16)
INTERNATIONAL INTERNAL	H2b		0.11***	0.08*		0.07**	0.06*		0.04	0.04
NETWORK			(2.57)	(1.67)		(2.18)	(1.73)		(1.24)	(1.02)
EXTERNAL NETWORK	H3a	0.10**		0.04	0.03		0.02	0.16***		0.09**
		(2.41)		(0.62)	(1.10)		(0.48)	(4.25)		(1.96)
INTERNATIONAL EXTERNAL	H3b		0.14***	0.11		0.03	0.02		0.19***	0.09
NETWORK			(2.64)	(1.46)		(0.96)	(0.37)		(4.01)	(1.58)
Control variables										
ENTERPRISE SIZE		0.04**	0.04***	0.03**	0.02	0.01	0.01	0.03***	0.04***	0.03**
		(2.29)	(2.70)	(2.00)	(1.47)	(1.42)	(1.17)	(2.65)	(2.94)	(2.41)
INDUSTRY DUMMIES		YES	YES	YES	YES	YES	YES	YES	YES	YES
$P(Y=1\mid X=\bar{x})$		0.26	0.26	0.26	0.11	0.11	0.11	0.15	0.15	0.15
N		679	679	679	679	679	679	679	679	679
Model χ^2 (d.f.)		161.71(16)***	165.68(16)***	167.48(18)***	83.66(16)***	86.74(16)***	87.04(18)***	206.98(16)***	207.25(16)***	211.12(18)***
Pseudo R^2		0.20	0.20	0.20	0.15	0.16	0.16	0.29	0.29	0.30

* p<0.10; ** p<0.05; *** p<0.01. All regressions are estimated with a constant. Marginal effects (M.E.) are given with the z statistics in parentheses. M.E. are calculated at the means of the regressors in the case of continuous data and for discrete change from 0 to 1 in the case of dichotomous variables. The results for industry dummies are omitted from the table.

Table 2 Regression results continued

Dependent variables	HYP	TURNOVER FROM IMPROVED PRODUCTS			TURNOVER FROM NEW PRODUCTS			TURNOVER FROM NOVEL PRODUCTS		
Estimation model: tobit		Model 1	Model *2*	Model 3	Model 1	Model *2*	Model 3	Model 1	Model *2*	Model 3
Independent variables		*M.E.*	*M.E.*	*M.E.*	*M.E.*	*M.E.*	*M.E.*	*M.E.*	*M.E.*	*M.E.*
R&D	H1	0.18***	0.19***	0.18***	0.26***	0.27***	0.26***	0.16***	0.16***	0.16***
		(3.64)	(3.79)	(3.57)	(4.93)	(5.03)	(4.73)	(3.52)	(3.50)	(3.42)
INTERNAL NETWORK	H2a	0.07**		0.04	0.08**		0.03	0.05**		0.01
		(2.01)		(0.97)	(2.15)		(0.61)	(2.05)		(0.44)
INTERNATIONAL INTERNAL	H2b		0.07**	0.05		0.10***	0.09**		0.08***	0.07**
NETWORK			(2.07)	(1.34)		(2.81)	(2.08)		(2.80)	(2.13)
EXTERNAL NETWORK	H3a	0.08**		0.06	0.09**		0.06	0.02		0.01
		(2.39)		(1.30)	(2.30)		(1.12)	(0.92)		(0.30)
INTERNATIONAL EXTERNAL	H3b		0.08**	0.04		0.09**	0.04		0.03	0.02
NETWORK			(2.02)	(0.69)		(2.02)	(0.75)		(0.89)	(0.46)
Control variables										
ENTERPRISE SIZE		0.01	0.02*	0.01	0.01	0.01	0.003	0.004	0.002	0.0003
		(1.27)	(1.64)	(1.00)	(0.65)	(0.69)	(0.27)	(0.39)	(0.24)	(0.03)
INDUSTRY DUMMIES ARE		YES	YES	YES	YES	YES	YES	YES	YES	YES
P(Y | a<X<b)		0.16	0.16	0.16	0.19	0.18	0.18	0.10	0.09	0.09
N		664	664	664	664	664	664	679	679	679
Model χ^2 (d.f.)		90.95(16)***	90.76(16)***	93.64(18)***	120.51(16)***	124.49(16)***	126.26(18)***	67.31(16)***	72.75(16)***	73.04(18)
Pseudo R^2		0.05	0.05	0.05	0.06	0.07	0.07	0.05	0.06	0.06
Number of observations censored at zero		533	533	553	509	509	509	590	590	590

* p<0.10; ** p<0.05; *** p<0.01. All regressions are estimated with a constant. Marginal effects (M.E.) are given with the z statistics in parentheses. M.E. are calculated at the means of the regressors in the case of continuous data and for discrete change from 0 to 1 in the case of dichotomous variables. The results for industry dummies are omitted from the table.

Looking at the regression results in Table 2, we find strong support for hypothesis 1 which suggests that internal sources via R&D are important in the generation of innovations. The variable R&D is the strongest and most significant independent variable across all models.

In relation to Hypothesis 2a, we find a positive association between internal networks and innovation performance supported in Model 1 for almost all indicators of innovation performance. Exceptions are NOVEL PRODUCT INNOVATION and SUSTAINED PRODUCT INNOVATION. Examining the fuller model, Model 3, the positive and significant association between internal networks *per se,* and innovation performance disappears. With respect to hypothesis 2b, which states that there is a positive association between international internal networks and innovation performance over and above internal networks *per se,* this, too, is supported. Model 2 shows that the variable INTERNATIONAL INTERNAL NETWORKS is positively and significantly associated with all indictors of innovation performance and Model 3 shows that this association is greater over and above an association with internal networks irrespectively of their location.

With respect to Hypotheses 3a and b, which state that there is a positive link between external networks and innovation, a similar pattern emerges. Both EXTERNAL and INTERNATIONAL EXTERNAL NETWORKS are positively and strongly significantly related to innovation performance. Model 3, however, suggests that there are no additional effects of INTERNATIONAL EXTERNAL NETWORKS over and above EXTERNAL NETWORKS in the case of PRODUCT INNOVATION, SUSTAINED PRODUCT INNOVATION and TURNOVER FROM IMPROVED and NEW PRODUCTS, i.e. there is no positive association between international external networks once we control for external networks *per se.* This suggests that benefits are greater when the external network is

within geographical reach, i.e. lies within the same country – in this case the UK. This is, however, not true where new-to-market innovations are concerned. Here, Model 3 suggests that INTERNATIONAL EXTERNAL NETWORKS are more conducive to increased innovation performance.

With respect to ENTERPRISE SIZE Table 2 indicates that this is positively correlated to product innovation, sustained product innovation and turnover from improved products, whereas ENTERPRISE SIZE is unrelated to the remaining indicators of innovations. Finally, there are strong INDUSTRY effects with chemicals and pharmaceuticals, communication equipment and scientific instruments, and post and telecommunication services having the highest positive impact on innovation performance. In the following section we discuss the findings presented here and their implications; we shall also point towards areas of limitations as well as possible questions for future research.

6. Discussion and conclusions

The paper starts with a discussion of possible sources of knowledge acquisition specifically in terms of the enterprise's own generation versus transfer from other sources. The former – own generation – can take place via solo activities or via collaborative activities. A discussion on issues related to the transfer of knowledge follows.

On the assumption that various sources of knowledge are likely to have a positive impact on innovation, we then formulate five hypotheses in relation to: acquisition via own development of knowledge and innovation; acquisition via intra-firm knowledge transfer and acquisition via collaborative agreements. For each of the last two cases we develop two hypotheses: one related to internal networks and

external collaborative agreements in general; and one related to their international dimension.

Empirically we measure the impact of own generation sources of knowledge leading to innovation activities via an indicator of sustained in-house R&D activity. We capture intra-firm knowledge transfer via a variable indicating whether the enterprise belongs to a company with an internal network of subsidiaries; acquisition via external collaboration is considered through a variable designed to capture innovation-specific agreements between the surveyed enterprise and external partners. The variables on R&D and collaborative agreements derive from CIS data, while the variable on internal networks derives from the WoW database. Dynamic elements are introduced via the use of CIS2 and CIS3 data.

Following an analysis of data sources and methodology we present the results of our regressions. These show that R&D expenditure is the most important of the three sources of innovation considered.

The second most important factor in the regression results are intra-firm knowledge transfers. Here, it is in particular the international dimension of intra-firm networks which impacts positively on enterprises' innovation performance. Our findings suggest that enterprises which, through companies' internal networks, are able to tap into resources located in different countries, and, therefore, different national systems of innovation, are more likely to introduce new-to-market products and have a higher share of turnover from new products.

Turning to the effects of knowledge acquisition via collaborative agreements, our findings suggest that cooperations increase the rate of incremental innovation. For example, we find a significant impact of cooperation on innovation and continuous product innovation (which may be new to the firm or new to the firm's market);

however, we do not find that cooperation matters in terms of new-to-market innovations. This seems to indicate that enterprises which are at the forefront of innovation rely to a lesser extent on knowledge sources from outside the company. A possible explanation for this result is that such enterprises may be less inclined to engage in collaborative agreements on innovation because they may fear that their own knowledge on their new products may leak out to rival firms.

On the issue of relevance of the international dimension we find that it matters in the case of intra-firm networks but not in the case of external collaborations. There are two possible and compatible explanations for this result. First, that the relationship between international external collaborations and internal networks is one of substitution more than complementarity: a result corroborated by the correlation coefficients presented and discussed in Appendix A. Second, that this regression result may be that subsidiaries are less likely to engage in international collaborations and that they are the ones most responsible for our results. In order to draw firmer conclusions we would need to probe further into possible divergence of behaviour between those enterprises that are HQs of a company and those that are subsidiaries: an issue we intend to research on at later stage.

With respect to firm size we find that it is positively correlated to continuous and perhaps more incremental types of innovations, but not to new-to-market innovations; however the results are not significant. Finally, and as expected, the sectoral environment an enterprise operates in matters with respect to innovation. In the case of our sample we find that enterprises which operate in the chemical and pharmaceutical sectors, communication equipment and scientific instruments and telecommunication services are much more innovative than enterprises operating in the remaining technological environments.

These initial results warrant more research on the effects on innovation performance of different sources of knowledge by the enterprises and companies as well as on the international dimensions of such arrangements. For example, another separate dimension on sources and innovation has to do with the nature of the enterprise surveyed. Within the CIS database, the surveyed enterprises may belong to a foreign company – in which case they are part of a transnational corporation – or to a domestic company which may or may not be a transnational. Within the enterprises part of a domestic company some are subsidiaries and some are the HQs of the company, while in the case of a foreign transnational company the enterprise surveyed will always be a subsidiary. This issue has been explored by Castellani and Zanfei (2006) in the case of Italian enterprises and a positive association between HQ and innovation performance was found. In this perspective it would be interesting to consider[10], for example, whether the involvement in collaborative agreements and their impact on innovation performance vary according to the position of the surveyed enterprise and specifically: whether the enterprise is more likely to engage in cooperation agreements if it is the HQ of a company rather than a subsidiary; and whether the impact on innovation performance differs. If that is the case it would point – inter alias – to the fact that subsidiary have less freedom to engage in external innovation-related agreements.

[10] As mentioned, we plan to develop this part of the work at a later stage.

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Appendix A The relationship between internal networks and external collaborative agreements on innovation

Here we analyse the relationship between internal networks and external innovation-related collaborative agreements and in particular whether such a relationship is likely to be one of *substitution* or *complementarity*. In other words and ceteris paribus, is an enterprise which is part of an internal network more or less likely to seek external innovation cooperation? Similarly, is an enterprise with access to an international internal network, because it is part of a TNC, more or less likely to seek external innovation linkages internationally or within the UK?

These questions cannot be answered *a priori*. It may be argued that the existence of internal networks gives the enterprise an opportunity to engage in external collaborations and, therefore, that the two types of linkages – internal and external – develop as complements within either the national or international dimension. On the other hand, it may be argued that an enterprise that has access to knowledge in other locations via the internal network of which it is part – be they within the national territory or international – has less need to seek costly and risky external cooperative agreements; therefore, in this perspective, the relationship will be seen as one of substitution. Both cases are plausible and it may be that in reality the relationship is, partly, sector-specific. For example, in sectors where innovation-specific cooperative agreements are very risky and/or firms aim at appropriating their knowledge internally, e.g. research-intensive sectors, the trend might be more towards the establishment of internal channels of knowledge development and spread rather than external ones.

There is another aspect of the complementarity v substitution relationship between internal and external agreements which we should highlight. According to the organizational structure of – and the control mechanisms within – the company, the surveyed enterprise may or may not have a large degree of autonomy in forging external networks. The degree of autonomy is likely to be higher with regard to external networks within the country in which the enterprise operates – in our case the UK – than for external linkages abroad.

In fact, the probability of our enterprise engaging in external innovative linkages abroad may depend on a variety of elements and specifically. First, whether the headquarters of the company – let's call it company X – favour such a strategy and give autonomy for its development. Second, whether the foreign country – say France – does or does not have subsidiaries of company X located within it. If it does, it seems likely that the external firms and institutions in France will forge collaborative agreements directly with the French subsidiary rather than the British one. We would therefore expect enterprises belonging to TNCs with internal networks in many countries to be less likely to engage directly in external cooperations abroad: the company's Head Quarters of other foreign subsidiaries may do it instead.

This discussion on the relationship between internal networks and external collaborations leads us to the following conclusions.

1. The extent to which enterprises that are part of an internal network engage in external agreements may partly depend on the autonomy they have from the HQ.
2. An enterprise that is part of a wide internal international network may be less likely to be involved in international external networks because the

subsidiary(ies) in the foreign country or the HQs will take over the task of forging those external linkages. This may point to a relationship of substitution between international internal networks and international external collaborations.

3. In spite of the conclusion in 3 regarding international linkages, our conclusion regarding linkages in general is that there is no a priori reason why internal and external networks as a whole should be complementary or substitute: enterprises that belong to internal networks are not necessarily – a priori – likely to engage in external cooperations; the outcome may be sector-specific.

Whatever the relationships between internal networks and innovation-related external collaborations on and whatever the ex ante reasons for the establishment of internal and external networks, ex post we expect a positive innovation performance.

To shed some light on the complementarity vs. substitution relationship in our sample we present in Table A1 the inter-correlations between internal and external networks.

For total enterprises both coefficients are positive and significant. However the coefficient for international internal and international external network is lower than the one for total internal and external networks. This might be a sign that indeed those enterprises that belong to international internal networks are less likely to engage in international external collaborative agreements as the linkages abroad would be gorged either by HQs or by the enterprises in the foreign country as highlighted in point 2 above. We were therefore expecting a relationship of substitution; however, the full analysis of the relationship would require a country by country assessment, quite beyond the scope of this paper. The low positive coefficients may point to substitution in those countries where there are both subsidiaries of companies and external collaborations with complementarity for those countries where the company does not have direct internal networks. The sectors results are mostly positive; the size and significance of the coefficients is affected by the size of the samples.

Table A1. Inter-correlations between internal and external networks

Industry sectors	Number of observations	Internal network and external networks *in toto*	International internal network and international external networks
All enterprises	**538**	**0.21*** **	**0.16*** **
Food, beverages and tobacco	31	0.26	0.25
Textiles, leather, publishing and printing	86	0.24*	0.1
Chemicals and pharmaceuticals	24	0.38†	0.08
Non-metallic and metal products	106	0.34***	0.34***
Machinery and equipment	108	0.12	0.13
Communication equipment	56	0.37**	0.2
Manufacturing not elsewhere classified	74	0.31**	-0.06
Wholesale, retail and trade	46	0.02	0.09
Transport services	41	0.21	-0.04
Financial, insurance and telecommunication	47	-0.09	0.31*
Other business activities	60	0.04	0.16

† p<0.1; * p<0.05; ** p<0.01; *** p<0.001.

Appendix B Inter-correlations between the dependent and independent variables analysed in the regression models

Variables		1	2	3	4	5	6	7	8	9	10	11	12
1	PRODUCT INNOVATION	1.00											
2	NOVEL PRODUCT INNOVATION	0.64	1.00										
3	SUSTAINED PRODUCT INNOVATION	0.82	0.59	1.00									
4	TURNOVER FROM IMPROVED PRODUCTS	0.53	0.32	0.44	1.00								
5	TURNOVER FROM NEW PRODUCTS	0.52	0.45	0.45	0.28	1.00							
6	TURNOVER FROM NOVEL PRODUCTS	0.35	0.55	0.26	0.23	0.63	1.00						
7	R&D	0.33	0.29	0.38	0.16	0.21	0.11	1.00					
8	INTERNAL NETWORKS	0.19	0.11	0.14	0.11	0.09	0.06	0.08	1.00				
9	INTERNATIONAL INTERNAL NETWORKS	0.24	0.16	0.21	0.14	0.15	0.11	0.13	**0.62**	1.00			
10	EXTERNAL NETWORKS	0.25	0.17	0.33	0.15	0.18	0.07	0.23	0.23	0.25	1.00		
11	INTERNATIONAL EXTERNAL NETWORKS	0.24	0.15	0.28	0.16	0.16	0.06	0.16	0.19	0.28	**0.72**	1.00	
12	ENTERPRISE SIZE	0.16	0.11	0.16	0.10	0.03	0.01	0.11	0.57	0.45	0.26	0.20	1.00

Variables 1 to 6 are the dependent variables. Variables 7 to 10 the independent variables, followed by the control variables 11 and 12. For presentational purposes industry dummies have been excluded from the table.

Correlations>0.05, $p<0.1$; correlations>0.08, $p<0.05$; correlations>0.10, $p<0.01$.