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The Effects of National and International Interaction on Innovation: Evidence from the Irish CIS: 2004-6

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Abstract

This paper analyses the importance of decisions to interact nationally and internationally on the likelihood of process and product innovation for a sample of Irish firms. The key contribution is to provide an empirical test of the relative importance of geographically proximate versus distant interaction, using a two-step procedure to remove potential endogeneity in interaction decisions. In doing so it finds that *only national* and *only international* interaction have the expected positive effects on the probability of innovation, while engaging in *both national and international* interaction has no effect. The findings support hypotheses on the importance of both geographically proximate and distant interaction for innovation, though the lack of significance for *both national and international* interaction means there is no evidence to support the proposition that these forms of interaction are complementary.

Introduction

This paper empirically tests the importance of geographically proximate and distant knowledge sources for innovation by Irish businesses. Originating in the work of Porter (1990), Krugman (1991) and Scott (1988), the hypothesis that geographically proximate interaction is important for innovation has come to dominate the innovation literature. However, recent work has questioned this by suggesting that distant interaction, or a combination of proximate and distant interaction might also be important (Boschma, 2005; Bathelt et al, 2004). The paper's key contribution is to conduct a detailed econometric test of these hypotheses for a sample of Irish businesses. In doing so it provides insights into whether *national*, *international* or a combination of *both* forms of interaction is more important for innovation. The paper also tests whether the importance of the types of interaction varies depending on the type of innovation considered, analysing *product only*, *process only* and *both product and process* innovation.

Increasingly, innovation is seen as a process of interactive learning (Kline and Rosenberg 1986; Lundvall 1995) characterised by firms engaging in external interaction with a variety of agents to acquire knowledge to complement or overcome deficiencies in the business' existing knowledge stock (Nonaka, Toyama and Konno 2001). According to Glaesar, Kallal, Scheinkman and Shleifer *"intellectual breakthroughs must cross hallways and streets more easily than oceans and continents"* (1992: 1127). Boschma (2005) suggests that spatial proximity enhances interactive learning and therefore innovation by stimulating other dimensions of proximity such as cognitive, organizational, social and institutional proximity. Spatial proximity may be associated with more face-to-face interaction, thereby enhancing the benefits of interactive learning (Rallet and Torre 1999; Storper and Venables 2004). This arises as tacit knowledge may be more easily understood and assimilated by those with shared personal experiences and possibly only by those who contribute to its development.

Therefore, the transmission of tacit knowledge is improved by strong ties between actors, which is facilitated by geographic proximity (Lissoni 2001; Gertler 2003).

However, recent case study evidence (Asheim and Isaksen 2002; Wolfe, Davis and Lucas 2005; Bramwell, Nelles and Wolfe 2008) and industry analyses (Gertler and Levitte 2005; Weterings and Ponds 2009) have questioned the premise that geographically proximate interaction is more important than distant interaction for innovation. Indeed, Boschma (2005) has argued that geographical proximity is neither a necessary or sufficient condition for organizational learning. Moreover, Boschma (2005) and Gertler and Levitte (2005) suggest that clusters which rely solely on proximate interaction risk stagnation due to a lack of exposure to new ideas. Bathelt, Malmberg and Maskell (2004) argue that most dynamic and creative clusters possess both deep local linkages and strong non-local linkages to other clusters.

The contribution of this paper is to empirically test, using data from the Irish Community Innovation Survey (CIS), the importance of proximate and distant interaction on the likelihood of innovation in a sample of Irish firms (Central Statistics Office 2009). The paper uses an innovation production function (Oerlemans, Meeus and Boekema 1998; Freel 2003; Roper, Youtie, Shapira and Fernández-Ribas 2010) augmented to incorporate measures distinguishing between whether a firm has engaged in (i) *only national* interaction, (ii) *only international* interaction or (iii) *both national and international* interaction. This facilitates an empirical test of the importance of 'local buzz' (Storper and Venables 2004) and/or 'global pipelines' (Bathelt et al. 2004) for innovation to be conducted. The key contribution is to test these hypotheses while distinguishing between firms which engage in *product only* innovation, *process only* innovation and *both product and process* innovation. A two-step procedure is adopted to address potential endogeneity in firms' decisions to interact.

The remainder of the paper is structured as follows. The next section presents a review of the literature on knowledge, geographical proximity and innovation and the development of hypotheses to be tested. This is followed by an outline of the model employed. The data are then summarized, followed by the presentation and interpretation of the empirical results. The final section concludes and outlines possible areas for future research.

Knowledge, Proximity and Innovation

Howells (2002) and Lissoni (2001) argue that innovation is of vital importance, not only for business success, but also for economic growth and social wellbeing. Knowledge, which is crucial for innovation, is defined by Howells (2002) as a dynamic framework from which information can be stored, processed and understood. In distinguishing between tacit and codified knowledge (Polanyi 1966), Freel (2003) argues that the former plays a key role in the innovation process. Tacit knowledge cannot be easily transmitted as it is individual and specific and may involve the acquirer making changes to existing behavior. Therefore, tacit knowledge can be more easily understood and assimilated by people with similar personal experiences and possibly even only by those who have contributed to its development (Howells 2002). This implies that the transmission of tacit knowledge is enhanced by strong social linkages between actors (Lissoni 2001).

Lundvall (1988), Kline and Rosenberg (1986) and Nonaka et al. (2001), when viewing interactive learning as a positive source of knowledge, suggest that external linkages can be exploited for business innovation. When firms innovate they utilise, combine and transform existing knowledge into a new product or process. However, internal knowledge is often not sufficient and external knowledge is frequently required (Howells 2002). Bathelt et al. (2004) suggest that firms engage in external knowledge sourcing to complement their existing knowledge or to overcome deficiencies in their internal knowledge. Similarly, Romijin and Albu (2002) and Gertler and Levitte (2005) note that external networking and interaction may be viewed as an important source of knowledge for innovation, with firms learning through interaction.

Interaction may take place with market-based agents, such as customers and suppliers, and non-market-based agents, such as higher education institutes and public research facilities. The form of interaction may range from contractual collaboration with an agent to social or informal, perhaps unintentional, networking. For the purposes of this paper interaction is defined as active participation with market and non-market agents on innovation activities, where both parties do not need to benefit commercially. The advantage of this definition is that it relates to occasions where knowledge, and more especially tacit knowledge, might reasonably be transferred.

Porter (1990), Krugman (1991) and Scott (1988) imply that the effectiveness of learning by interaction lessens as geographical distance increases. Geographical proximity facilitates face-to-face communication which in turn assists the transfer of tacit knowledge (Romijin and Albu 2002; Wolfe et al. 2005). Rallet and Torre (1999) set out three assumptions about tacit knowledge and innovation which suggest geographical proximity is important for external interaction and, therefore, innovation. First, innovation activities are highly tacit knowledge intensive. Second, the more tacit knowledge required, the greater the need for face to face interaction to successfully transfer the knowledge. Finally, the higher the frequency of face to face interaction that is required the greater the need for permanent geographical proximity. The authors note that the importance of these factors depends on the type of tacit knowledge required and also the nature of the business. These assumptions underpin the concept of a cluster, where the local 'buzz' is characterized by frequent, face to face interaction between members, thereby facilitating the transfer of tacit knowledge through knowledge spillovers (Storper and Venables 2004). This concept is also closely associated with the theories of localization economies developed by Marshall (1920) and Porter (1998). Based on these theories, which promote the importance of proximity for knowledge sharing, the following hypothesis is proposed:

> Hypothesis 1: Geographically proximate interaction positively affects the probability that firms will engage in process and product innovation.

However, while Freel (2003) notes that there is an assumption in the literature that proximity is important for knowledge transfer, he points out that improvements in ICT, facilitate non-local interaction. Boschma (2005) argues that, while in theory geographical proximity along with cognitive proximity are sufficient for interactive learning to take place, other forms of proximity, such as organizational proximity, may act as substitutes for geographical proximity. Rallet and Torre (1999) find evidence from research projects to support this argument. This is consistent with Bathelt et al. (2004), who argue that distance may not be the most important determinant of interaction and that other factors may play an important role in explaining the patterns of interaction by firms. They suggest that access to new knowledge is not confined to local interaction but also occurs through 'global pipelines'.

Weterings and Boschma (2009) suggest regional and non-regional knowledge flows differ in the nature of the knowledge they offer; with local linkages being characterised by frequent, perhaps unintentional interaction, while non-regional interaction may require more planning and coordination. Thus, while perhaps being more costly to initiate, global pipelines, once established, may prove to be an important source of knowledge for innovation. Furthermore, Rallet and Torre (1999) argue that temporary proximity may provide an alternative to permanent geographical proximity. Temporary proximity occurs when individuals are not permanently located in close proximity but still have frequent face-to-face communication. This is promoted, for example, by reductions in travel costs which facilitate individuals traveling for meetings, thus allowing distant agents to have more regular face-to-face interaction. Indeed, Weterings and Ponds (2009) find evidence that non-regional knowledge flows are actually more important than regional knowledge flows for innovation. This suggests the second hypothesis to be considered:

> Hypothesis 2: Geographically distant interaction positively affects the probability that firms will engage in process and product innovation.

Finally, Gertler and Levitte (2005) note that there may be a complementary relationship between local knowledge sources and global 'pipelines'. This view is shared by Bathelt et al. (2004) who argue that the co-existence of local buzz and global pipelines provides potential advantages to businesses. Boschma (2005) suggests that problems associated with too much geographical proximity, resulting in spatial lock-in, may be overcome by the establishment of non-local linkages. This implies that, firms experiencing blind spots from too much geographical proximity, may also engage in distant interaction, the result being an improvement in their innovation performance. This hypothesis, that both proximate and distant interaction may be more important than proximate interaction, is difficult to test. This is because it is not possible to identify the reasons why firms engage in both forms of interaction. As a result, the following hypothesis is proposed:

> Hypothesis 3: The co-existence of geographically proximate and distant interaction positively affects the probability that firms will engage in process and product innovation

The paper does not formulate hypotheses about the relative importance of geographically proximate, distant and both proximate and distant interaction for innovation. While the literature underpinning Hypothesis 1 may imply the primacy of geographically proximate interaction (see for example Porter, (1998)), those proposing the importance of distant linkages have been careful not to assert that they are more important than proximate interaction (Boschma, 2005). The process of innovation involving the discovery of knowledge in pursuit of commercial gain differs from firm to firm and is subject to trial and error (Kline and Rosenberg, 1986). As a result, this paper focuses on the importance of each kind of interaction.

The key contribution of this paper is to estimate the extent to which externally sourced knowledge, from interaction with geographically proximate and distant agents, affects the probability of innovation. In doing so it provides an empirical test of the three hypotheses outlined in this section. As Ireland is a small country, with a population of approximately 4.2 million (Central Statistics Office 2010) only slightly exceeding the EU's upper limit for a NUTS 2 region (EuroStat 2010a)[i], national interaction is considered to be geographically proximate while international interaction is deemed to be distant interaction. This distinction is consistent with Gertler and Levitte's (2005) analysis of Canada. The methodology enables the identification of whether national interaction, international interaction or a combination of the two are important. A two-step procedure is also adopted to address potential endogeneity in firms' decisions to interact.

Turning to innovation output, this paper considers product and process innovation (Pittaway, Robertson, Munir, Denyer and Neely 2004). Product innovation is the introduction of new or significantly improved products or services which may be new to the firm or new to the market. Process innovation is the implementation of a new or significantly improved production process, distribution method or support activity.[ii] These definitions are consistent with Schumpeter's (1934) concepts of innovation and conform to those in the Oslo Manual (OECD 2005). The paper adds to the literature by distinguishing between firms' decisions to engage in *process only*, *product only* and *both process and product* innovation. Distinguishing between process and product innovation is often difficult as new processes may facilitate the development of new products, while new products may require new processes to be introduced (Gordon and McCann 2005). The methodology employed therefore explicitly allows for the decisions to engage in each of the three forms of innovation to be interdependent. This is an advance on Roper et al (2008) and Jordan and O'Leary (2008) who, in analysing process and product innovation, do not distinguish between firms which engage in both forms of innovation and firms which engage in only one form of innovation. The methodology employed by these other studies also assumes that the decisions to engage in process and product innovation are independent.

In addition to highlighting the importance of 'local buzz' and 'global pipelines' for innovation, Bathelt et al. (2004) also note the key role played by the internal capabilities of the firm in acquiring and utilising knowledge sourced from outside the business. Gertler and

Levitte (2005) state that internal resources, such as R&D expenditure and human capital are important drivers of firms' innovation performance. Cohen and Levinthal (1990) highlight that a firm's absorptive capacity is an important determinant of the effectiveness with which a firm can capture external knowledge.

Apart from internal knowledge generation and external linkages a number of firm specific factors may also affect innovation performance. Whether the firm is indigenous or foreign owned may play a role in explaining innovation performance, which is an issue of particular relevance to Ireland given its reliance on foreign direct investment (Jordan and O'Leary 2008; Roper et al. 2008) Similarly, the sector in which a firm operates may impact on its likelihood of innovation (Pavitt 1984; Oerlemans et al. 1998).

Methodology

The focus of this paper is to analyse the importance of national and international interaction for firm level innovation. An innovation production function is used to model the effect of different kinds of knowledge sourcing on firms' probability of innovating. It describes the relationship between the propensity of a firm to innovate and a range of explanatory factors (Griliches 1979; Oerlemans et al. 1998; Roper 2001; Janz, Lööf and Peters 2003; Love and Mansury 2007). Equation (1) presents the innovation production function to be estimated:

$$\begin{aligned} IO_{ih} &= \delta_h + \phi_{1h} KS_{Nat,i} + \phi_{2h} KS_{Int,i} + \phi_{3h} KS_{Nat\&Int,i} \\ &+ \lambda_h R\&D_i + \gamma_h CI_i + \eta_{hk} Z_{ki} + \varepsilon_{1hi} \end{aligned} \qquad (1)$$

Where IO_{ih} represents a categorical variable describing whether firm i engages in one of four possible innovation outcomes. These outcomes, designated h, are whether (i) the firm does not innovate, (ii) the firm engages in *process only* innovation, (iii) the firm engages in *product only* innovation or (iv) the firm engages in *both product and process* innovation. This categorical variable defines the full set of possible innovation outcomes for a firm in a mutually exclusive specification.

The variables $KS_{Nat,i}$, $KS_{Int,i}$ and $KS_{Nat\&Int,i}$ are a series of variables representing whether firm *i* engaged in external knowledge sourcing. Three variables indicate whether firms interact (i) only at the national level, (ii) only at the international level or (iii) at both the national and international levels. The outcome category, no interaction, is the reference category for each interaction variable. This series of binary variables are exhaustive and mutually exclusive, capturing the entire spectrum of possible interaction outcomes. The values ϕ_{1h}, ϕ_{2h} and ϕ_{3h} represent the coefficients for the different knowledge sourcing activity. Hypotheses 1, 2 and 3 respectively stipulate that ϕ_{1h}, ϕ_{2h} and ϕ_{3h} are positive and significant for each type of innovation output.

The inclusion of a variable indicating whether the firm performs R&D is standard in this literature as R&D is considered to be a crucial input in the innovation process (Griliches 1992; Freel 2003). $R\&D_i$ is a variable indicating the expenditure of firm *i* on intramural R&D per employee during the reference period. It is hypothesized that λ_h is positive. Also included is CI_i, a variable indicating the expenditure by a firm on the acquisition of machinery, equipment or computer hardware or software to produce new or significantly improved products or services during the reference period. It is hypothesized that γ_h is positive.

Z_{ki} represents a vector of *k* variables which may impact on firm *i*'s ability to innovate (Oerlemans et al. 1998; Freel 2003; Roper et al. 2008). The vector Z_{ki} is defined as:

$$Z_{ki} = (\text{Sector}_i, \text{Employment}_i, \text{IrishOwned}_i, \text{Human Capital}_i)$$

where $Sector_i$ represents the sector in which the firm operates, $Employment_i$ is a continuous variable representing the number of employees (expressed in natural logs), $IrishOwned_i$ is a binary variable representing whether the firm is Irish owned or not and $Human\ Capital_i$ is an ordinal measure of the extent to which the business reports a lack of qualified personnel as prohibitory to innovation. The human capital measure is used as a proxy for the firms' absorptive capacity. Doran and O'Leary (2011), in their estimation of the CDM model for Irish firms, employ the same measure to control for the influence of human capital. While it is more common to use the proportion of the workforce with third level education, this is not available in the Irish CIS.

When estimating Equation (1) two factors must be considered; first, the most appropriate estimation technique and second, the potential endogeneity of independent variables in the model. Regarding the first issue, since the dependent variable in Equation (1) is nominal, that is both mutually exclusive and exhaustive, a multinomial probit estimation is appropriate. The choice of a multinomial probit model over a multinomial logit model is due to the latter suffering from the independence of irrelevant alternatives (IIA) assumption (Greene 2008). A violation of this assumption in a multinomial logit model may result in misleading inferences (McFadden 1974; Horowitz and Savin 2001). In the context of a decision by firms to engage in *process only*, *product only* or *both process and product* innovation, the IIA assumption would appear unrealistic. It would be anticipated for example that, should a firm introduce a new product innovation, it would also consider whether there is a need to introduce a new process innovation (Swann 2009). Therefore, the multinomial probit model is preferred over the multinomial logit model in this instance (Cameron and Trivedi 2005). This technique controls for the simultaneous nature of firms' decisions to innovate and is a methodological contribution to literature in this area which typically treats innovation decisions as independent of each other (Freel 2003; Love and Mansury 2007; Jordan and O'Leary 2008; Roper et al. 2008).

Secondly, there is the issue of potential endogenity of certain independent variables in equation 1. The potentially endogenous variables are the three external knowledge sourcing variables. To address potential endogenity of the knowledge sourcing variables a two-step procedure is adopted (Crépon, Duguest and Mairesse 1998; Griffith, Huergo, Mairesse and Peters 2006; Hall, Lotti and Mairesse 2009). This involves initially estimating three knowledge sourcing equations, deriving the predicted probability of firms engaging in interaction activity from each of these equations and utilizing these predicted probabilities as instruments in Equation (1). Adopting this two-step approach allows for the estimation of Equation (1) while controlling for the endogenity of $KS_{Nat,i}$, $KS_{Int,i}$ and $KS_{Nat\&Int,i}$.

As noted by Hall et al. "[u]*sing these predicted probabilities instead of the observed indicators is a way to address the issue of potential endogeneity (and measurement errors in variables) of the knowledge inputs*" (2009: pg 23). The use of predicted values, obtained from estimates of the knowledge sourcing equations (2) through (4), and their inclusion in the innovation production function, equation (1), is a practical way of controlling for potential endogeneity between firms' decisions to source knowledge for innovation and their innovation performance. Griffith et al. (2006) point out that there is likely to be unobservable factors, not captured by the CIS survey, that impact both firms' decisions to engage in knowledge sourcing activity and their decisions to innovate. As these factors are unobservable they are omitted from the analysis. These omitted factors may increase or decrease both the likelihood of a firm sourcing knowledge and innovating. This would imply that the ϕ coefficients in equation (1) would be biased upward or downward as the *KS* variables and the error term ε would be positively correlated, due to the same omitted variables putting upward or downward pressure on both the *KS* variable and the error term ε. This two-step procedure is used by Hall et al. (2009), Griffith et al. (2006) and Crépon et al. (1998) and removes the correlation between the *KS* variable and the error term ε by generating predicted values for *KS* as suitable instruments. This provides unbiased estimates of the ϕ coefficients, provided the instruments are uncorrelated with the error term ε.

Equations (2) through (4) present the knowledge sourcing equations to be estimated.

$$KS_{Nat,i} = \alpha_o + \alpha_1 Employment_i + \alpha_2 IrishOwned_i + \alpha_3 Sector_i + \alpha_4 HF_i + \varepsilon_{2i} \quad (2)$$

$$KS_{Int,i} = \beta_o + \beta_1 Employment_i + \beta_2 IrishOwned_i + \beta_3 Sector_i + \beta_4 HF_i + \varepsilon_{3i} \quad (3)$$

$$KS_{\mathrm{Nat\&Int,i}} = \chi_o + \chi_1 Employment_i + \chi_2 IrishOwned_i + \chi_3 Sector_i + \chi_4 HF_i + \varepsilon_{4i} \quad (4)$$

The first three variables are defined as above. It is anticipated that firm size, ownership and the sector in which a firm operates may impact on the likelihood of a firm engaging in any of the knowledge sourcing activities outlined above (Roper et al. 2008; Doran and O'Leary 2011). The variable HF_i represents a series of factors that might hamper innovation. Following from Hall et al. (2009) and Griffith et al. (2006) a clear distinction is made between the variables which impact on knowledge sourcing and innovation. The measures are fully discussed in the next section.

Equations (2) through (4) are estimated using a series of probit models. Once estimated, the predicted values of the dependent variables are obtained.. Similar to Hall et al. (2009) the predicted values for the full sample are estimated without constraining the data to firms which have engaged in knowledge sourcing (Crépon et al. 1998; Doran and O'Leary 2011). The predicted values derived are not the linear predictions of the equations but the predicted probabilities, therefore, the values obtained are still bound between zero and one. These values are then used as instruments in the innovation production function equation (1) in line with Crépon et al. (1998), Griffith et al. (2006) and Hall et al. (2009).

The Irish CIS: 2004-06

This paper uses data from the Irish CIS, which is conducted jointly by Forfás (Ireland's national policy advisory body) and the Irish Central Statistics Office. The survey sample is 1,974 firms, representing a 48% response rate, which is high relative to other Irish studies (Roper 2001; Jordan and O'Leary 2008). The survey is directed to companies employing more than 10 persons engaged in selected sectors (see Forfás (2008) for a discussion on the sectoral framework utilised). Consistent with the OECD's Oslo manual, the survey includes a reference period, which in this case is 2004 to 2006, for innovation inputs and outputs (OECD 2005).

The Irish CIS distinguishes between product and process innovation. Product innovation is defined as the introduction of a new or improved good or service with respect to its capabilities, user friendliness, components or sub-systems. These innovations must be new to the business, but they do not need to be new to the market. Process innovation is defined as the implementation of a new or improved production process, distribution method, or support activity for goods or services. Again, process innovations must be new to the business but not necessarily the market. Due to the separate treatment of product and process innovation in the CIS it is possible to identify if firms engage in either form of innovation or both. The descriptive statistics displayed in Table 1 indicate that 14% of firms engage in *process only* innovation, 13% engage in *product only* innovation and 20% engage in *both product and process* innovation. This implies that 47% of the sample can be classified as innovators.

[Table 1 Around here]

The key focus of this paper is whether the geography of external interaction matters for innovation. The CIS provides information on firms' external interaction. It defines external interaction as active participation with other enterprises or non-commercial institutions on innovation activities, where both parties do not need to benefit commercially (Central Statistics Office 2009). Six external agents are identified in the survey and used in this study. These are interaction with customers, suppliers, competitors, consultants, higher education institutes and public research facilities. Firms also provide information on the location of these external agents indicating whether they are located in; Ireland, Northern Ireland, Europe, the United States or any other country.

Perhaps due to the restricted definition of interaction as active participation on innovation activities, the incidence of interaction with a possible six different interaction agents at the various geographic levels is low with responses ranging from 1% to 3% of the sample. As a result this paper aggregates interaction in two ways. First, as already outlined, firms are classified based on whether they interact at (i) a national level, (ii) an international level or (iii) both national and international levels. Second, interaction is aggregated into a single binary variable, where one indicates a firm engaged in interaction with any of six possible interaction agents.[iii]

The benefit of this approach is that the aggregate variables possess a significantly increased ratio of interaction to non-interaction, thereby enhancing the reliability of the results. This compensates for the loss of some information due to the inability to distinguish between the effects of interaction for each of the six external agents on innovation performance. Table 1 shows that 9% of firms interact only at a national level, 8% interact only internationally and 5% interact at both national and international levels. The proportion of firms which engage in either form of external interaction is therefore 22%.

Intramural *R&D* is defined as expenditure by the business on creative work undertaken within it to increase the stock of knowledge for developing new and improved products and processes. The mean expenditure by firms on intramural R&D per employee is €2,270 with a standard deviation of €12,419. The variable *CI* relates to the acquisition of advanced machinery, equipment and computer hardware or software to produce new or significantly improved products or processes. The mean expenditure per employee on capital for innovation is €3,490 with a standard deviation of €32,952.

The sectors surveyed in the CIS are the complete range of manufacturing sectors and three services sectors: *Wholesale, Transport, Storage and Communication; Financial Intermediation;* and *Computer, Architecture* and *Engineering Services.* This paper classifies manufacturing into *High-Tech Manufacturing* and *All Other Manufacturing*. The services sector *Computer, Architecture and Engineering Services* is also classified as high-technology.[iv] Table 1 shows that 27% of the sample is in either of the high-technology sectors with 30% in *All Other Manufacturing,* 35% in *Wholesale, Transport, Storage and Communication* and 8% in *Financial Intermediation.*

It can also be observed in Table 1 that the mean size of firms is 124 workers with a standard deviation of 524. A total of 74% of the firms surveyed are indigenous, with a significant portion of the remaining 26% of foreign-owned firms being branch plants of foreign multi-nationals operating in Ireland.

Table 2 presents the descriptive statistics for the hampering factors utilized in the knowledge sourcing equations. It shows that 49% of firms indicate that a lack of human capital was not important for innovation, while 24%, 19% and 8% reported low, medium and high importance for innovation, respectively. Regarding the other hampering factors, *lack of funds within the enterprise* and *innovation costs too high* are the most commonly reported to be of medium or high importance to firms when innovating. While a *lack of information on markets*, *a lack of information on technology* and *difficulty in finding cooperation partners* are reported by firms as being relatively less important for innovation activities.

[Table 2 Around here]

Appendix 1 presents a correlation matrix of the key variables to identify potential multicollinearity. It can be observed that the pair-wise correlations between all variables are relatively low, suggesting that the potential for estimates to be biased through multicollinearity is low.

Empirical Results

Table 3 presents the results of the probit estimations of Equations (2) through (4). Individual probit estimates are presented, as a rho test of a multivariate probit estimate of the model indicated no significant difference between the individual probit estimations and the multivariate probit estimation.

[Table 3 Around here]

It can be observed that larger firms are more likely than smaller firms to engage in all forms of external knowledge sourcing. This result, which is consistent with Roper, Du et al. (2008) and Doran and O'Leary (2011), suggests economies of scale in terms of the acquisition of externally sourced knowledge. Irish owned firms are more likely to engage in national interaction while foreign-owned firms are more likely to engage in either international interaction or both national and international interaction. This may result from foreign-owned firms' access to networks of international contacts or may suggest that Irish-owned firms are perhaps more inward looking than their foreign counterparts.

There is mixed evidence on the extent to which a sectoral effect is present in how firms source external knowledge for innovation. Firms in the *All Other Manufacturing* sector are less likely to engage in national interaction, while firms in the *Financial Intermediation* sector are less likely to engage in international interaction, relative to all other sectors. Firms in all sectors are equally likely to engage in both national and international interaction.

Firms which report a lack of funds within their enterprise are more likely to engage in national interaction. This may result from these firms lacking the internal financial resources to find or engage in cooperation with external knowledge sources on an international scale. Firms which perceive a lack of outside finance for their business are less likely to engage in national interaction. Firms which perceive the cost of innovation to be too high are less likely to engage in national interaction, perhaps suggesting the return from national interaction is insufficient to justify the cost of innovation. Finally, a lack of information on technology increases the probability of firms engaging in national interaction but reduces the probability of engaging in both national and international interaction. This may signify that firms turn first to national knowledge sources to obtain information on technology before consulting international knowledge sources.

Table 4 presents the results of the multinomial probit estimation of Equation (1). The predicted probabilities derived from Equations (2) though (4) are used as instrumental values for the knowledge sourcing variables in this equation, thereby addressing potential endogenity in the knowledge sourcing variables. The reference category for the dependent variable is not introducing any form of innovation during the reference period, 2004 to 2006. The first column displays the results of this estimation for *process only* innovation, the second for *product only* innovation and the final for both product and process innovation.

[Table 4 Around here]

The results show that for all forms of innovation activity, engaging in *only national* and in only international interaction has positive and statistically significant effects on the likelihood of innovation. However, engaging in *both national and international* interaction has no significant impact on firms' likelihood of innovation. These results provide support for hypotheses 1 and 2. They imply that firms which engage in geographically proximate or distant interaction are more likely to innovate. However, no support is found for hypothesis 3 that the co-existence of geographically proximate and distant interaction positively affects the probability that firms will engage in process and product innovation. This suggests that firms gain a benefit from specializing in either national or international interaction, and not by engaging in both types of interaction simultaneously.

The finding of a positive national interaction effect is consistent with Porter (1998), Rallet and Torre (1999) and Storper and Venables (2004) who argue that geographical proximity is vital for the transmission of tacit knowledge. The hypotheses proposed by Bathelt et al. (2004) and Boschma (2005) that geographically distant interaction has a positive effect on the likelihood of innovation is also supported by the results presented in Table 4. However, the suggestion by Bathelt et al. (2004) and Boschma (2005) that the co-existence of geographically proximate and distant interaction positively affect the likelihood of innovation is not supported by the findings in this paper. There is therefore no evidence of a complementary relationship between national and international interaction for innovation performance in Irish businesses.

These results support empirical studies such as (Romijin and Albu 2002; Wolfe et al. 2005) that show the importance of geographical proximity for innovation. They also support recent case studies (Asheim and Isaksen 2002; Wolfe et al. 2005; Bramwell et al. 2008) and industry analyses (Gertler and Levitte 2005; Weterings and Ponds 2009) which suggest that distant interaction is important for innovation. This paper contributes to the empirical literature in three ways. First, it uses the CIS which is a comprehensive large-scale survey covering a range of businesses in differing sectors. Second, it uses an econometric methodology that allows for the endogeneity of external interaction decisions of different geographical scale in the innovation production function to be estimated. Finally, it designs the methodology to directly estimate the impact of these external interaction decisions on the likelihood of engaging in three different kinds of innovation output.

Internal knowledge sources are also hypothesised to play an important role for innovation. It is perhaps surprising that intramural R&D expenditure, which relates to "creative work undertaken within the enterprise" (Central Statistics Office 2009) has no effect on the probability of process innovation. It is, however, notable that capital spending on advanced machinery, equipment and computer hardware or software to produce new or significantly improved processes has a strongly positive effect, which is consistent with Griffith et al. (2006). In addition, a perceived lack of human capital has a positive effect on the likelihood of process innovation. This may suggest that firms which experience a lack of human capital innovate in order to overcome their deficiency (Doran and O'Leary 2011). Interestingly, neither the size of the business, its ownership or the sector it belongs to have any statistically significant effect on the probability of process innovation.

Intramural R&D expenditure has positive and significant effects on *product only* and *both process and product* innovation. This is consistent with Crépon et al. (1998), Janz et al. (2003) and Johansson and Lööf (2009) who show that intramural R&D is a key driver of product innovation. It can also be observed that firms' acquisition of capital for the production of new products or processes has a significantly positive effect on the likelihood of firm's engaging in these forms of innovation. This suggests that firms spending more per employee on capital for the production of new products or process are more likely to engage in *product only* and *both process and product* innovation (Griffith et al. 2006).

Table 4 also reveals that Irish firms are less likely to engage in *product only* innovation than foreign firms, many of whom are branch plants of foreign multi-nationals. This result is consistent with Doran and O'Leary's (2011) and Jordan and O'Leary's (2008) investigations of Irish data. Table 4 also shows that a perceived lack of human capital has a positive impact on both forms of innovation output. This may be explained by innovative firms being more likely to encounter such a lack of human capital for innovation (Doran and O'Leary 2011).

Despite the considerable degree of uniformity in the determinants of *product only* and *both process and product* innovation, there are some differences. Larger firms are more likely to engage in *both process and product* innovation, thus pointing to an economies of scale effect. The significance of the sectoral controls also varies. Relative to *High-Tech Manufacturing*, firms in the *Wholesale, Transport, Storage and Communication* sector are less likely to introduce only product innovation while firms in the *All Other Manufacturing*, *Wholesale, Transport, Storage and Communication* and *Computer, Architecture and Engineering Services* sectors are less likely to introduce both product and process innovation relative to firms in the *High Technology Manufacturing*.

Conclusions and Implications

This paper has analysed the importance of geographically proximate and distant interaction for the innovation performance of Irish firms. It tests three hypotheses; that geographically proximate, geographically distant and the co-existence of proximate and distant interaction positively affect the likelihood of innovation. An augmented innovation production function is used to assess the impact of these forms of external interaction on the likelihood of three types of innovation output; *process only* innovation, *product only* innovation and *both process and product* innovation. Key methodological contributions are the estimation of a multinomial probit model to control for the simultaneous nature of firms' decisions to innovate and a two-step procedure to remove potential endogeneity in interaction decisions (Roper et al. 2008; Hall et al. 2009; Doran and O'Leary 2011).

The results indicate that external interaction plays an important role in the innovation decisions of Irish firms. *National only* interaction and *international only* interaction are found to have the expected positive effect on the probability of engaging in all forms of innovation activity considered. The paper therefore provides support for both Porter (1998), Rallet and Torre (1999) and Storper and Venables (2004) on the importance of geographically proximate interaction for innovation and for the arguments of Bathelt et al. (2004) and Boschma (2005) that distant interaction will positively affect the likelihood of innovation. However, the lack of a significant role for performing *both national and international* interaction questions Bathelt et al. (2004) and Boschma (2005) proposition that both together are important for innovation. Irish-based businesses engaging in *both national and international* interaction are not, as expected, more likely to engage in product and/or process innovation. Boschma (2005) has suggested that businesses may turn to international interaction to counteract blind spots from too-much geographical proximity. These results indicate that such businesses may be experiencing difficulties in coordinating the multiple sources of knowledge to the detriment of their innovation performance. However, given the finding in Table 3 that foreign-owned businesses are more likely to engage in *both national and international* interaction, it is also possible that these businesses, which in the Irish case are likely to have strong international linkages (Jordan and O'Leary, 2005), may face difficulties when they source knowledge from within the Irish national innovation system. These potential explanations would best be investigated using detailed case study analysis.

From a policy perspective, the results support government efforts to encourage firms engaging in innovation to form national clusters and networks in order to promote geographically proximate interaction. Previously, in an Irish context this approach has been criticized, with Jordan and O'Leary (2008) and Roper (2001) finding no evidence that geographical proximity increases the frequency of external interaction. However, these papers do not test the direct effect of proximate and distant interaction on innovation output and fail to account for the potential endogeneity of knowledge sourcing decisions in firms' innovation production function. The results presented in this paper also suggest that it is not just national clusters which promote innovation, but that international linkages also have a significantly positive effect. This raises the question as to whether Irish innovation policy, which is focused on geographical clustering, could be complemented by aiding firms engaging in international networks as an alternative to clustering.

The paper also raises a number of questions for further research. While measuring the effects of the incidence of interaction on firms' innovation output, this paper does not investigate the frequency and nature of interaction with specific external agents. This hypothesis cannot be tested using CIS data. Case study and survey data of this kind would enable a more detailed analysis of the effectiveness of transferring tacit knowledge for innovation via face-to-face communication compared to other communication methods. Also, the availability of panel data would facilitate the analysis of how firms' knowledge sourcing activities and innovation outputs evolve over time. Clearly interaction during a reference period may not be linked to innovation output in the same period. There is therefore a need, as pointed out by Boschma (2005), to study the dynamics of the interaction-innovation nexus. Finally, it is worth considering, from a policy perspective, whether these results hold for other countries. Indeed, application of the methodology for larger samples might eliminate the need to aggregate external interaction for the range of agents, thereby uncovering a rich vein of evidence for policymakers.

References

Asheim, B. and A. Isaksen (2002). Regional Innovation Systems: The Integration of Local 'Stickey' and Global 'Ubiquitous' Knowledge. *Journal of Technology Transfer* 27(1): 77 - 86.

Bathelt, T., H. Malmberg and P. Maskell (2004). Clusters and Knowledge: Local Buzz, Global Pipelines and the Process of Knowledge Creation. *Progress in Human Geography* 28(1): 31-56.

Boschma, R. (2005). Proximity and Innovation: A Critical Assessment. *Regional Studies* 39(1): 61-74.

Bramwell, A., J. Nelles and D. Wolfe (2008). Knowledge, Innovation and Institutions: Global and Local Dimensions of the ICT Cluster in Waterloo, Canada. *Regional Studies* 42(1): 101-116.

Cameron, A. and P. Trivedi (2005). *Microeconometrics: Methods and Applications*.(New York, Cambridge University Press).

Central Statistics Office (2009). *Community Innovation Survey: 2004-06*.(Dublin, Ireland, Stationery Office).

Central Statistics Office. (2010). "People and Society." Retrieved 16th June 2010, from http://cso.ie/statistics/Population1901-2006.htm.

Cohen, W. and D. Levinthal (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly* 35(1): 128-152.

Crépon, B., E. Duguest and J. Mairesse (1998). Research, Innovation and Productivity: An Econometric Analysis at the Firm Level. *Economics of Innovation and New Technology* 7(2): 115-158.

Doran, J. and E. O'Leary (2011). External Interaction, Innovation and Productivity: An Application of the Innovation Value Chain for Ireland. *Spatial Economic Analysis* 6(2): 199 - 222.

European Commission (2003). 2003 European Innovation Scoreboard: Technical Paper No 4 Sectoral Innovation Scoreboards. *European Trend Chart on Innovation*.

EuroStat. (2010a). "The NUTS Classification." Retrieved 16th June 2010, from http://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/regional_statistics/nuts_classification.

EuroStat. (2010b). "Regional Statistics." Retrieved 16th June 2010, from http://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/regional_statistics/data/database.

Forfás (2008). *Community Innovation Survey 2004-2006 – First Findings*.(Dublin, Forfás Statistics Bulletin).

Freel, M. (2003). Sectoral Patterns of Small Firm Innovation, Networking and Proximity. *Research Policy* 32(5): 751-770.

Gertler, M. (2003). Tacit knowledge and the economic geography of context, or the undefinable tacitness of being (there). *Journal of Economic Geography* 3(1): 75-99.

Gertler, M. and Y. Levitte (2005). Local Nodes in Global Networks: The Geography of Knowledge Flows in Biotechnology Innovation. *Industry and Innovation* 12(4): 487-507.

Glaesar, E. L., H. D. Kallal, J. A. Scheinkman and A. Shleifer (1992). Growth in Cities. *Journal of Political Economy* 100(6): 1126-1152.

Gordon, I. and P. McCann (2005). Innovation, Agglomeration and Regional Development. *Journal of Economic Geography* 5(5): 523 - 543.

Greene, W. (2008). *Econometric Analysis*.(United States, Pearson-Prentice Hall).

Griffith, R., E. Huergo, J. Mairesse and B. Peters (2006). Innovation and Productivity Across Four European Countries. *Oxford Review of Economic Policy* 22(4): 483-498.

Griliches, Z. (1979). Issues in Assessing the Contribution of Research and Development to Productivity Growth. *Bell Journal of Economics* 10(1): 92-116.

Griliches, Z. (1992). The Search for R&D Spillovers. *The Scandinavian Journal of Economics* 94(Supplement): 29-47.

Hall, B., F. Lotti and J. Mairesse (2009). Innovation and Productivity in SMEs: Empirical Evidence from Italy. *Small Business Economics* 33(1): 13-33.

Horowitz, J. and N. Savin (2001). Binary Response Models: Logits, Probits and Semiparametrics. *The Journal of Economic Perspectives* 15(4): 43-56.

Howells, J. (2002). Tacit Knowledge, Innovation and Economic Geography. *Urban Studies* 39(5-6): 871-884.

Janz, N., H. Lööf and B. Peters (2003). Firm Level Innovation and Productivity: Is there a Common Story Across Countries? *C.F.E.E. Research.*

Johansson, B. and H. Lööf (2009). Innovation, R&D and Productivity. *Centre of Excellence for Science and Innovation Studies Electronic Working Paper Series* 159(January).

Jordan, D. and E. O'Leary (2005). The Roles of Interaction and Proximity for Innovation by Irish High-Technology Businesses: Policy Implications. *Quarterly Economic Commentary*(2): 86 - 100.

Jordan, D. and E. O'Leary (2008). Is Irish Innovation Policy Working? Evidence from Irish High-Technology Businesses. *Journal of the Statistical and Social Inquiry Society of Ireland* 37: 1-44.

Kline, J. and N. Rosenberg, Eds. (1986). *An Overview of Innovation*. The Positive Sum Strategy: Harnessing Technology for Economic Growth.(Washington, National Academy Press).

Krugman, P. (1991). Increasing Returns and Economic Geography. *The Journal of Political Economy* 99(3): 483 - 499.

Lissoni, F. (2001). Knowledge Codification and the Geography of Innovation: The Case of Brescia Mechanical Cluster. *Research Policy* 30(9): 1479 - 1500.

Love, J. and M. Mansury (2007). External Linkages, R&D and Innovation Performance in US Business Services. *Industry and Innovation* 14(5): 477-496.

Lundvall, B. (1995). *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*.(London, Pinter).

Lundvall, B. E., Ed. (1988). *Innovation as an interactive process: From user-producer interaction to the national system of innovation*. Technical Change and Economic Theory.(London, Pinter Publishers).

Marshall, A. (1920). *Principles of Economics*.(London, MacMillan).

McFadden, D. (1974). Conditional Logit Analysis of Qualitative Choice Behavior.in: P. ZarembkaEds. *Frontiers in Econometric*. (New York, Academic Press.

National Competitiveness Council (2009). *Driving Export Growth: Statement on Export Competitiveness*.(Dublin Forfás).

Nonaka, I., R. Toyama and N. Konno, Eds. (2001). *SECI, Ba and Leadership: a Unified Model of Dynamic Knowledge Creation*. Managing Industrial Knowledge: Creation, Transfer and Utilisation.(Thousand Oaks, Ca, Sage).

OECD (2005). *The Measurement of Scientific and Technological Activities Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data*.(France, OECD Publication).

Oerlemans, L., M. Meeus and F. Boekema (1998). Do Networks Matter for Innovation? The Usefullness of the Economic Network Approach in Analysing Innovation. *Journal of Economic and Social Geography* 89(3): 298-309.

Pavitt, K. (1984). Sectoral Patterns of Technical change: towards a taxonomy and theory. *Research Policy* 13(6): 343-374.

Pittaway, L., M. Robertson, K. Munir, D. Denyer and A. Neely (2004). Networking and Innovation: A Systematic Review of the Evidence. *International Journal of Management Reviews* 5/6(3&4): 137-168.

Polanyi, M. (1966). *The Tacit Dimension*.(London, Routledge and Kegan Paul).

Porter, M. (1990). *The Competitive Advantage of Nations*.(United States of America, The Free Press).

Porter, M. E. (1998). Clusters and the New Economics of Competition. *Harvard Business Review* 76 (6): 77 - 90.

Rallet, A. and A. Torre (1999). Is Geographical Proximity Necessary in the Innovation Networks in the Era of Global Economy? *Geojournal* 49(4): 373 - 380.

Romijin, H. and M. Albu (2002). Innovation, Networking and Proximity: Lessons from Small High Technology Firms in the UK. *Regional Studies* 36(1): 81 - 86.

Roper, S. (2001). Innovation, Networks and Plant Location: some evidence from Ireland. *Regional Studies* 35(3): 215-228.

Roper, S., J. Du and J. Love (2008). Modeling the innovation value chain. *Research Policy* 37(6-7): 961-977.

Roper, S., J. Youtie, P. Shapira and A. Fernández-Ribas (2010). Knowledge, Capabilities and Manufacturing Innovation: A USA-Europe Comparison. *Regional Studies* 44(3): 253 - 279.

Schumpeter, J. (1934). *The Theory of Economic Development*.(Cambridge, U.S., Harvard University Press).

Scott, A. (1988). *New Industrial Spaces*.(United States of America., Pion).

Storper, M. and A. Venables (2004). Buzz: face-to-face contact and the urban economy. *Journal of Economic Geography* 4(4): 351 - 370.

Swann, P. (2009). *The Economics of Innovation: An Introduction*.(Cheltenham, UK, Edward Elgar).

Weterings, A. and R. Boschma (2009). Does spatial proximity to customers matter for innovative performance?: Evidence from the Dutch software sector. *Research Policy* 38(5): 746-755.

Weterings, A. and R. Ponds (2009). Do regional and non-regional knowledge flows differ? An empirical study on clustered firms in life sciences and computing services. *Industry and Innovation* 16(1): 11 - 31.

Wolfe, D., C. Davis and M. Lucas (2005). *Global Networks and Local Linkages*.(Kingston, McGill-Queen's University Press).

Table 1: Descriptive Statistics of Variables

Variable	Statistic	Standard Deviation
Company Specific Factors		
Employment[1]	124	525
Irish Owned (0/1)	74%	n/a
R&D (€) [2]	2,270	12,419
Capital for Innovation (€) [2]	3,490	32,952
Sector		
High-Tech Manufacturing (0/1)	14%	n/a
All Other Manufacturing (0/1)	30%	n/a
Wholesale, Transport, Storage and Communication (0/1)	35%	n/a
Financial Intermediation (0/1)	8%	n/a
Computer, Architecture and Engineering Services (0/1)	13%	n/a
Innovation Output		
Product Only Innovation (0/1)	14%	n/a
Process Only Innovation (0/1)	13%	n/a
Product and Process Innovation (0/1)	20%	n/a
Interaction		
National Only (0/1)	9%	n/a
International Only (0/1)	8%	n/a
National and International Interaction (0/1)	5%	n/a

Note 1: From CSO Central Business Register
2: Per employee.

Source: Community Innovation Survey: 2004-2006

Table 2: Descriptive Statistics of Hampering Factors for Innovation (Percentage of Respondents)

Variable	*Not Important*	*Low Importance*	*Medium Importance*	*High Importance*
Lack of funds within the enterprise	48	20	18	14
Lack of finance from sources outside the enterprise	57	20	14	9
Innovation costs too high	50	17	20	13
Lack of qualified personnel	49	24	19	8
Lack of information on technology	52	29	15	4
Lack of information on markets	51	28	16	5
Difficulty in finding cooperation partners for innovation	59	24	11	6

Source: Community Innovation Survey: 2004-2006

Table 3: Probit Estimation of Equations (2) through (4)

	National	International	Both National & International Interaction
Constant	-2.9873***	-2.0821***	-3.4218***
	(0.2820)	(0.2751)	(0.3703)
Employment	0.2142***	0.1145**	0.2782**
	(0.0435)	(0.0460)	(0.0548)
Irish-owned	0.3912***	-0.2842**	-0.4806***
	(0.1393)	(0.1255)	(0.1657)
Sector[2]			
All Other Manufacturing	-0.2678*	-0.0489	0.3145
	(0.1609)	(0.1595)	(0.2204)
Wholesale, Transport, Storage & Communication	-0.2376	-0.2051	0.1905
	(0.1638)	(0.1717)	(0.2386)
Financial Intermediation	-0.1477	-0.4767**	0.0685
	(0.2221)	(0.2674)	(0.3040)
Computer, Architecture & Engineering Services	0.1154	0.1155	0.3660
	(0.1819)	(0.1875)	(0.2648)
Hampering Factors			
Lack of funds within the enterprise	0.3131***	0.0379	0.0578
	(0.0645)	(0.0775)	(0.1006)
Lack of finance from sources outside the enterprise	-0.1305*	-0.0278	0.0946
	(0.0721)	(0.0809)	(0.1043)
Innovation costs too high	-0.1508**	0.0969	0.1363
	(0.0705)	(0.0738)	(0.0977)
Lack of qualified personnel	-0.0146	0.0346	0.1392
	(0.0785)	(0.0822)	(0.1067)
Lack of information on technology	0.1941**	-0.1471	-0.3122**
	(0.0997)	(0.1123)	(0.1499)
Lack of information on markets	-0.0509	0.0721	-0.0740
	(0.0885)	(0.0911)	(0.1262)
Difficulty in finding cooperation partners for innovation	0.1107	0.0553	0.1350
	(0.0714)	(0.0811)	(0.1010)
Log Likelihood	-326.27	-302.43	-160.47
No. Observations	1974	1974	1974
Wald Chi2	73.04	39.24	70.15
Prob>Chi2	0.0000	0.0000	0.0000

Note 1: *** significant at 99%, ** significant at 95%, * significant at 90%.

2: High-Tech Manufacturing is the reference category.

3: Each equation is estimated using a single probit model. When estimated jointly using a multivariate probit model a significance test of the rho values suggests that there is no significant difference between the estimated multivariate probit model and the single equation models.

Table 4: Multinomial Probit Estimation of Equation (1)

	Process Innovation	Product Innovation	Both Process & Product Innovation
Constant	-1.8679***	-1.3231***	-2.2458***
	(0.3666)	(0.3632)	(0.3438)
External Interaction			
National Interaction[3]	4.2339***	2.7046*	4.6189***
	(1.5437)	(1.6515)	(1.4802)
International Interaction[3]	10.6273**	8.8862*	14.8290***
	(5.1054)	(5.1223)	(4.7543)
National and International Interaction[3]	-1.0841	-0.2168	-3.6757
	(3.1681)	(3.1697)	(2.9576)
Internal Knowledge Generation			
R&D[2]	-0.0644	0.2331***	0.2129***
	(0.0648)	(0.0588)	(0.0550)
CI[2]	0.3879***	0.2366***	0.3734***
	(0.0534)	(0.0566)	(0.0520)
Employment	0.0504	-0.0036	0.2087***
	(0.0657)	(0.0697)	(0.0645)
Irish-owned	-0.0956	-0.2890*	-0.2018
	(0.1688)	(0.1709)	(0.1619)
Human Capital	0.1627***	0.2694***	0.3440***
	(0.0590)	(0.0602)	(0.0571)
Sector[4]			
All Other Manufacturing	0.0813	-0.2719	-0.3296*
	(0.1995)	(0.1933)	(0.1805)
Wholesale, Transport, Storage & Communication	-0.0640	-0.4326**	-0.4652**
	(0.2232)	(0.2160)	(0.2041)
Financial Intermediation	0.3385	-0.3331	-0.3863
	(0.3015)	(0.3094)	(0.2976)
Computer, Architecture & Engineering Services	-0.1882	-0.0118	-0.3596*
	(0.2160)	(0.1990)	(0.1912)
Log Likelihood			-2074.98
No. Observations			1974
Wald Chi2			469.14
Prob>Chi2			0.0000

Note 1: *** significant at 99%, ** significant at 95%, * significant at 90%.

2: Per employee

3: Indicates the use of fitted values derived from the estimation of Equations (2) to (4).

4: High-Tech Manufacturing is the reference category

Appendix 1: Correlation Matrix of Variables

	National Interaction	International Interaction	National & International Interaction	Human Capital	Irish-owned	R&D[1]	CI[1]	Employment
National Interaction	1							
International Interaction	-0.0435	1						
National & International Interaction	-0.0312	-0.0288	1					
Human Capital	0.0833	0.0481	0.0519	1				
Irish-owned	0.016	-0.0873	-0.1212	0.0052	1			
R&D[1]	0.0063	0.0576	0.1851	0.1051	-0.1235	1		
CI[1]	-0.0115	0.0734	0.0317	0.0341	-0.0915	0.1698	1	
Employment	0.0733	0.0172	0.1496	0.0522	-0.1215	0.036	0.0086	1

Note 1: Per employee
Source: The Irish Community Innovation Survey 2004-06

Endnotes

[i] By definition NUTS2 regions must contain a population of between 800,000 and 3,000,000 people (EuroStat 2010a). The combined population of Ireland's two NUTS 2 regions is approximately 4,200,000 in 2006, only slightly in excess of this upper limit (Central Statistics Office 2010). Further to this, the combined area of Ireland is approximately 6,900 square kilometers, which is only 100 square kilometers greater than that of the Cumbria NUTS2 region in the UK (EuroStat 2010b). This evidence justifies the identification of national interaction as being geographically proximate.

[ii] Product and process innovation are not the sole forms of innovation a firm can implement. The Oslo manual identifies four types of innovation; product, process, marketing and organizational innovation (OECD 2005). While each of these kinds of innovation is important for firm performance the Irish CIS only relates R&D and external interaction to product and process innovation. This limits this analyse to the consideration of these two forms of innovation.

[iii] Further to this, interaction between firms and other group companies is excluded as this form of interaction is exclusive to non-Irish owned enterprises and is predominately international in scope.

[iv] The NACE Rev 1 codes selected are: *High-Tech Manufacturing* (24, 29, 30 - 35); *All Other Manufacturing* (10-14; 15-37 excluding high-tech, 40-41), *Wholesale, Transport, Storage and Communication* (51, 60-64), *Financial Intermediation* (65-67) and *Computer, Architecture and Engineering Services* (72, 74.2, 74.3). The definition of high-technology is taken from the OECD classification (European Commission 2003). Forfás consider *Computer, Architecture and Engineering Services* as part of

Ireland’s ICT sector (National Competitiveness Council 2009). For a fuller discussion see Jordan and O’Leary (2005; 2008).