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The Innovation Performance of Irish and Foreign-owned Firms: The Roles of R&D and networking

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Abstract

This paper contributes to the growing evidence that Irish and foreign-owned firms conduct their innovation activities differently in Ireland. It tests the Cohen and Levinthal (1990) hypothesis, separately for Irish and foreign-owned firms, that undertaking R&D and collaborating with external networks together enhance the probability of product and process innovation. In order to control for potential endogeneity of the external networking variables a two-step procedure is used with predicted probabilities used as instruments in the estimated production functions. Based on data from the Irish Community Innovation Survey 2006-08, the results suggest that Irish-owned firms which engage in external networks with public knowledge sources, while simultaneously undertaking R&D, are more likely to innovate than firms which perform these two activities individually. Irish-owned firms which engage in backward networking for product and forward networking for process innovation while also undertaking R&D are less likely to be innovative, perhaps suggesting a substitution effect. These results for Irish-owned firms provide some support for Cohen and Levinthal's (1990) hypothesis. However, foreign-owned firms seem to behave differently, being largely self-contained and relying exclusively on intramural R&D for innovation as the external networking

variables, both individually and when interacted with R&D, have no effect on innovation likelihood.

Key Words: Innovation, R&D, External Networking

I. Introduction

Ireland's resilience to the recent global downturn has been greatly influenced by its export performance driven by continuing strength from foreign-owned firms (Barry and Bergin, 2012). Indeed, Godard, Gorg and Hanley (2012) have shown that during the crisis, on average, foreign-owned firms did not behave any differently in terms of exit behaviour compared with Irish-owned firms. In contrast, this paper explores how Irish and foreign-owned firms conduct innovation in Ireland. It builds on Doran and O'Leary's (2011) suggestion that the Irish innovation system is dichotomous and more recent work by Doran et al. (2013) showing that Irish and foreign-owned firms operating in the country have fundamentally different relationships between R&D spending and the probability of innovation.

This paper pursues this line of research by empirically testing the hypothesis, associated with Cohen and Levinthal (1990), that the *interaction* of R&D effort and external networking is important in order to enhance a firm's probability of innovation. Cohen and Levinthal (1990) suggest that through the undertaking of R&D firms can develop higher levels of absorptive capacity thereby improving their ability to recognise and assimilate valuable external knowledge in order to introduce new products or processes. This suggests that the undertaking of both R&D and external networking may be central to the production of innovation output. The paper builds on existing international research on the innovation production function which typically treats R&D spending and the incidence of external networking as independent variables in explaining the probability or intensity of innovation output (see for example Roper, 2001 and Doran and O'Leary, 2011).

Given the finding by Doran et al. (2013) that Irish and foreign-owned firms experience different returns on R&D investment in Ireland, the paper explores whether there are differences in the relationship between R&D and networking in these firms. It employs a modified innovation production function following Crépon et al. (1998), which includes R&D spending, different forms of external networking and interaction terms between intramural R&D spending and the external networking variables. It first employs a likelihood-ratio test to determine whether it is necessary to estimate distinct models for Irish-owned and foreign-owned firms. Following Colombo and Garrone (1996), David et al. (2000) and Miotta and Sachwald (2003) who suggest that R&D and external networking are jointly determined, it controls for potential endogeneity and adopts a two-step procedure by instrumenting external networking (Crépon et al. 1998; Griffith et al. 2006; Hall et al. 2009; Doran, Jordan and O'Leary 2012).

The data used is from the Irish Community Innovation Survey (CIS) 2006-08. This survey, conducted jointly by the CSO and Forfàs, provides a sample of 2,181 firms (CSO 2010). It identifies the expenditure by Irish-owned and foreign-owned firms on intramural R&D and also whether these firms engage in external networking with a number of agents; including customers, suppliers, competitors, consultants, universities and public research institutes. Two distinct kinds of innovation output are available in the survey; product and process innovation.

Our results suggest that Irish-owned and foreign-owned firms differ significantly in the factors which drive their innovation performance. We find that Irish-owned firms benefit more from external networking than foreign-owned firms and that substitution and complementary effects are observed between networking and R&D for Irish-owned firms. These relationships do not

exist for foreign-owned firms. Indeed we find that foreign-owned firms benefit from the performance of internal R&D rather than external networking.

The remaining sections of the paper are structured as follows. Section II motivates the research by summarizing the debate on the innovation performance of Irish and foreign-owned firms. Section III outlines the hypotheses to be tested in more detail followed by a description of the data in Section IV. Section V outlines the model to be tested. Section VI presents the empirical results and the final section concludes and discusses the implications of the results.

II. The Innovation Performance of Irish and Foreign-owned Firms

It is well known that for the last 30 years Ireland has had a strong reliance on foreign direct investment (see for example Barry and Bradley, 1997). By 2009, foreign-owned firms based in Ireland accounted for 80% of Ireland's merchandise and services exports, mostly in pharmaceuticals and chemicals, medical and surgical equipment, computer and information services and financial and insurance services. The remaining 20% of exports are from Irish-owned businesses in the food and drink manufacturing and IT and computer services (Barry and Bergin, 2012). Typically, foreign-owned firms located in Ireland are affiliates of large mature international firms concentrated in high-technology sectors, while Irish-owned firms employ considerably smaller numbers than foreign affiliates on average and are more dispersed across the range of manufacturing and services sectors.

Over the last five decades Ireland has followed a unique development trajectory (O'Leary, 2015). Between 1970 and the beginning of the Celtic Tiger in the early 1990s, the imperative of increasing employment resulted in the government policy of industrialization by invitation. Over this period Irish industry consisted of foreign-owned industry, which was increasingly

seen as an alternative source of employment, and a weak indigenous base. Productivity levels in foreign-owned industry were higher as these businesses drew technology from parent firms and made little use of Irish research and development (Kennedy et al, 1988: 241). A lack of indigenous innovation was noted in the reviews of industrial policy conducted during the 1980s, 1990s and 2000s. (Telesis 1982; Culliton 1992 and Enterprise Strategy Group 2004).

Increasing recent emphasis by Irish and EU policymakers on innovation has resulted in an 11% annual average increase in real terms in public spending on higher education R&D between 2000 and 2008 There were also increased public support for business spending on R&D, with almost half of total grant funding from Enterprise Ireland and IDA Ireland to Irish and foreign-owned firms respectivelybeing linked to science and technology. Spending by businesses on R&D also increased but at a slower rate (Doran et al, 2013).

In terms of the sourcing of knowledge for innovation Doran and O'Leary (2011) have pointed to the dichotomous Irish innovation system with some firms sourcing knowledge from market agents while others more likely to source knowledge from universities and public research institutes. It has been suggested that this may reflect the science-push focus on Irish innovation policy with its concentration on business-university networking in high-technology firms, which are dominated by foreign-owned firms (Jordan and O'Leary, 2008; O'Leary, 2015).

Recent research by Doran, Jordan and O'Leary (2013) has found fundamentally different relationships between R&D spending and the probability of innovation by Irish and foreign-owned firms. Based on the CIS 2004-06, this study finds that Irish-owned firms are significantly more likely than foreign-owned to introduce new products as a result of intramural R&D spending. This occurs even though Irish-owned firms spend nearly 4 times less per worker than foreign-owned on this kind of R&D. It suggests that while all Irish-based firms face the same taxation incentives to engage in R&D, in terms of corporation tax and R&D tax

credits, foreign-owned firms are part of multi-national enterprises seeking to minimize the corporation's exposure to tax. This consideration may offset the imperative of developing new products and processes through intramural R&D expenditure and is less likely to be a factor conditioning the behaviour of Irish-owned firms, relatively few of whom are part of multi-national enterprises.

The present study therefore builds on Doran, Jordan and O'Leary (2013) by concentrating on the effects of the *interaction* of intramural R&D spending with external networking on the likelihood of innovation in Irish and foreign-owned firms. It considers the theory proposed by Cohen and Levinthal (1990), that innovation output is positively linked to the combination of creative effort associated with R&D and networking with external agents, be it public, backward, forward or horizontal. By investigating this hypothesis for both Irish and foreign-owned firms for the CIS 2006-8 the paper contributes to understanding of the innovation performance of Ireland's distinctive enterprise base.[i]

III Absorptive Capacity and Innovation Performance

The concept of absorptive capacity links R&D activity, external networking and innovation performance. R&D activity refers to the creative effort expended by the business in order to introduce new products and processes. It is assumed that the presence of an in-house R&D capacity is necessary in order to absorb external knowledge. This notion of absorptive capacity, introduced by Cohen and Levinthal, is important because *"the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends is critical to its innovative capabilities"* (1990: 8). This suggests that a necessary condition for innovation output is the combination of creative effort associated with R&D and networking with external agents such as customers, suppliers, competitors and public research bodies. It

is therefore vital to investigate the interaction between networking and R&D in terms of their effects on innovation output.

Cohen and Levinthal (1990) argue that the ability to evaluate and utilize outside knowledge is largely a function of the level of prior related knowledge, which includes basic skills and knowledge of recent technological developments in a given field. At the level of the firm they associate absorptive capacity with the conduct by the firm of its own R&D. According to Kline and Rosenberg the performance of R&D involves solving "problems all along the chain of innovation from the initial design to the finished production processes" (1986: 303).

Knowledge, which is clearly 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) and Freel (2003) argue 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 behaviour. Therefore, tacit knowledge can be more easily understood and assimilated by people with similar personal experiences and possibly even by those who have contributed to its development (Howells 2002). This implies that the transmission of tacit knowledge is enhanced by social linkages between actors (Lissoni 2001).

Lundvall (1988), Kline and Rosenberg (1986) and Nonaka, Toyama and Konno (2001), when viewing interactive learning as a positive source of knowledge, suggest that external networking can be exploited for the advancement of business innovation. For firms to innovate they utilise, combine and transform existing knowledge into a new product or process. However, internal knowledge is not sufficient and acquiring new knowledge from outside the firm is frequently required (Howells 2002). Bathelt et al. (2004) suggest that firms engage in

external networking 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 may be viewed as an important source of knowledge for innovation, with firms learning through interaction.

Following Cohen and Levinthal (1990) the key hypothesis to be tested in the paper is that the interaction between R&D spending and external networking has a positive effect on the probability of firms introducing new products and processes. The *a priori* expectation is that both Irish and foreign-owned firms which engage in higher levels of R&D will be better able to exploit the knowledge gained from external networking, due to their absorptive capacity. As a result, the hypothesis is that these firms will be more likely to introduce new products or processes. The paper therefore contributes to the understanding of the precise nature of the relationship between external networking and R&D, and how, when combined, these inputs impact on innovation performance. In addition by investigating these relationships for both Irish and foreign-owned separately, further evidence is provided on Ireland's enterprise base.

The paper builds on existing research on the innovation production function which typically treats R&D spending and the incidence of external networking as independent variables in explaining the probability or intensity of innovation output, for example Roper (2001) and Doran and O'Leary (2011). Following Colombo and Garrone (1996), David, Hall and Tool (2000) and Miotta and Sachwald (2003) who suggest that R&D and external networking are jointly determined, it adopts a two-step procedure whereby the external networking variables are estimated separately with predicted probabilities derived for use as instruments in the estimated production functions (Crépon et al. 1998; Griffith et al. 2006; Hall et al. 2009; Doran,

Jordan and O'Leary 2012). The next section outlines the data while the following section presents a more detailed outline of the modelling approach.

IV. Description of Data

The data set used in this paper is the Irish CIS 2006-08. This survey was conducted jointly by Forfás (Ireland's national policy advisory body) and the Central Statistics Office in Ireland. The survey is directed to companies employing more than 10 persons engaged in a range of manufacturing sectors, with selected service sectors (CSO 2010). The CSO and Forfás jointly conducted a postal survey in December 2009. Consistent with the OECD's Oslo manual, the survey includes a reference period, which in this case is 2006 to 2008, for innovation inputs and outputs (OECD 2005). A total of 4,650 surveys were issued with 2,181 responses. The motivation for the CIS survey is to provide a comprehensive survey of the innovation performance of Irish firms. The survey is conducted as part of the European wide CIS project and is completed every two years (CSO 2010).

Regarding the representativeness of the CIS, the rationale for choosing the Irish CIS as the basis of this analysis is that it provides the only large scale representative survey of the innovation activities of Irish firms. The survey is stratified to represent the diverse firm sizes and the composition of targeted sectors. A sample of 4,650 firms was selected from the full list of relevant enterprises on the CSO's Business Register. A census was then conducted of all firms with more than 50 people employed. Also, a census was taken of certain sectors, regardless of firm size, when the number of firms in that sector was low. A sample of firms was taken for the remaining sectors. Neyman allocation was used to select the sampling fraction in each of these remaining sectors and the average sampling fraction was

approximately 40%. The actual enterprises chosen were selected using random selection (see Forfás 2009 for further details).

In the sample there are 1,659 Irish-owned and 522 foreign-owned firms. Table 1 presents the descriptive statistics. 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. Firms indicate whether or not they have performed these types of innovations, resulting in a series of binary innovation variables. We can see that foreign-owned firms are substantially more likely to introduce both product and process innovation, with 45% and 49% of foreign-owned firms engaging in product and process innovation respectively compared to 27% and 34% for Irish-owned firms engaging in these forms of innovation.

Table 1: Descriptive Statistics of Variables

	Irish		Foreign Owned	
	Mean	St.Dev	Mean	St.Dev
Innovation(IO)				
Product Innovator (1/0)	26.58	n.a.	45.4	n.a.
Process innovator (1/0)	34.24	n.a.	49.23	n.a.
Networking (N)				
Public (1/0)	4.91	n.a.	7.77	n.a.
Backward (1/0)	7.77	n.a.	16.41	n.a.
Forward (1/0)	6.09	n.a.	11.78	n.a.
Horizontal (1/0)	2.61	n.a.	4.44	n.a.
Research & Development (RD)	€ 1,402	€ 3,042	€ 2,381	€ 3,821

Firm Specific Characteristics (Z)				
Employment (number)	63	216	172	307
Sector				
High-tech Manufacturing (1/0)	32.13	n.a.	23.37	n.a.
All Other Manufacturing (1/0)	6.45	n.a.	19.35	n.a.
Wholesale, Transport, Storage & Communication (1/0)	37.55	n.a.	27.39	n.a.
Financial Intermediation (1/0)	8.86	n.a.	17.05	n.a.
Computer, Architecture & Engineering Services (1/0)	15.01	n.a.	12.84	n.a.

[a]Sectoral definitions are based on NACE Rev2
[b]NACE Rev 2 codes given in brackets

Freel (2003), McCann and Simonen (2005) and Roper et al. (2008) highlight the importance of external networking for innovation. The Irish CIS provides information on whether firms engage in collaboration with customers, suppliers, consultants, competitors, universities and public research institutes in the development of new innovations. Collaboration involves active participation with other enterprises or non-commercial institutions on innovation activities, where both parties do not need to benefit commercially (CSO, 2010). This definition refers to formal networking and does not include the informal networking that may occur between firms. However, the advantage of this measure is that it relates to occasions where knowledge, and more especially tacit knowledge, might reasonably be transferred.

In line with Roper et al. (2008), this paper classifies these differing types of interaction into four categories; public networking (with universities and public research institutes), backward networking (with suppliers and consultants), forward networking (with customers) and horizontal networking (with competitors). Table 1 shows that foreign-owned firms are more likely to engage in each kind of networking than Irish-owned. In addition backward networking with suppliers and consultants are most common for both Irish and foreign-owned firms while horizontal networking is the least common.

This paper considers the intramural R&D expenditure, which is defined as creative work undertaken within the enterprise to increase the stock of knowledge for developing new and improved products and processes (OECD, 2005; Central Statistics Office, 2009). It can be seen in Table 1 that foreign-owned firms spend more per worker on average than Irish-owned firms. The mean spending per employee on intramural R&D for foreign- owned firms is €2,381 with a standard deviation of €3,821 while for Irish-owned firms it is € 1,402 with a standard deviation of € 3,042.

The Irish CIS targets a broad range of sectoral classes. The NACE Rev2 sectoral classifications are utilised by the Irish CSO to categorise firms into sectors. This paper follows these sectoral definitions and identifies nine broad sectors in which firms operate. Further information on the NACE Rev2 definitions can be obtained from EuroStat (2008).

Firm specific factors also included from the Irish CIS are the number of people employed by the enterprise. The mean size of Irish-owned enterprises is 63 persons while foreign-owned businesses on average employ 172.

V. The Empirical Model

The focus of this paper is to analyse the extent to which R&D and external networking complement one another. An innovation production function is used to model the effects of (i) different kinds of external networking, (ii) the performance of R&D and (iii) the interaction of R&D and external networking on firms' probability of innovating. Innovation production functions describe the relationship between the propensity of a firm to innovate and a range of

explanatory factors (Griliches 1979; Oerlemans, Meeus and Boekema 1998; Roper 2001; Janz, Lööf and Peters 2003; Love and Mansury 2007). Equation (1) presents the innovation production function to be estimated:

$$IO_{ih} = \beta_h + \phi_{1hj} N_{ji} + \phi_{2h} RD_i + + \phi_{3hj} N_{ji} * RD_i + \eta_{hk} Z_{ki} + \varepsilon_{1hi} \qquad (1)$$

Where IO_{ih} represents a categorical variable describing whether firm *i*, whether it be Irish or foreign-owned, engages in one of two possible innovation outcomes. These outcomes, designated *h*, are (i) whether the firm engages in process innovation or (ii) whether the firm engages in product innovation.

N_{ji} indicates a series of *j* binary external networking activities. These variables indicate whether firm *i* engages in public (with universities and public research institutes), backward (with suppliers), forward (with customers) or horizontal (with competitors) networking. Based on the discussion in the literature review it is hypothesised that the coefficients ϕ_{1j} will have a significantly positive effect on the likelihood of innovation. 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). RD_i is a variable indicating the natural logarithm of the expenditure of firm *i* on intramural R&D per employee during the reference period. It is hypothesized that ϕ_2 is positive. The variable $N_{ji} * RD_i$ captures the interaction between R&D and networking and is the chief focus of this paper. Following Cohen and Leninthal (1990) it is hypothesized that ϕ_3 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, Du and Love 2008). The vector Z_{ki} is defined as:

$$Z_{ki} = \left(\text{Sector}_i, \text{Employment}_i, \text{Irish Owned}_i, \text{Innovation Factors}_i\right)$$

where $Sector_i$ represents the sector in which the firm operates, $Employment_i$ is a continuous variable representing the number of employees (measured in natural logs) and $IrishOwned_i$ is a binary variable representing whether the firm is Irish owned or not. Innovation Factors represents a series of variables available from the Irish CIS which identify whether firms have experienced any barriers to their innovation activity. These variables include factors that might in the perception of firms hamper their innovation, including whether the market is dominated by established enterprises, uncertain demand for innovation output, the need to meet government regulations and excessive perceived risks. All variables are described in the Data section below.

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, as there are two innovation production functions (one for both product and process innovation) and there is a strong likelihood of common unobserved factors impacting on the likelihood of both types of innovation, a bivariate probit model is employed which takes into account possible correlation across the error terms of the two equations (Greene 2008). This procedure is common in the innovation literature (Griffith et al. 2006; Hall et al. 2009; Doran et al. 2012).

Secondly, to address potential endogenity of the external networking variables a two-step procedure is adopted (Crépon et al. 1998; Griffith et al. 2006; Hall et al. 2009). The issue of endogeneity in innovation production functions is discussed in papers such as Hall et al. (2009) and Griffith et al (2006) who note that firms which engage in innovation activity may also be more likely to engage in knowledge generation activities due to some unobservable factors intrinsic to the firm. If some unobservable factor has a positive effect on both the probability of a firm innovating and also engaging in external networking, this will manifest as upward bias in the coefficient estimates of our model. We treat this omitted variable issue as an endogeneity issue and generate instruments for the potential endogenous variables utilising the same procedure as Hall et al (2009) and Siedschlaga et al (2011).

This approach of using a two step procedure to control for potential endogeneity is frequently used in the innovation literature by studies which utilise CIS type data. For instance, Crespi and Zuniga (2012) utilise the same methodology to analyse the innovative behaviour of firms in six Latin American countries. Likewise Griffith et al. (2006) utilise this approach when employing CIS data to analyse the innovation performance of firms across four European countries. The methodology has also been employed in the context of SME innovation performance in Italy (Hall et al. 2009), for a sample of French and German firms using CIS data (Robin and Schubert, 2013), and to assess the impact of various different drivers of innovation in Hungarian firms (Halpern and Muraközy 2012). As a final example Huergo and Moreno (2011) discuss the application of this types of analysis to panel data.

Specifically, our two-step procedure involves initially estimating four external networking equations, deriving the predicted probability of firms engaging in interaction activity from each

of these equations and utilizing the resulting predicted probabilities as instruments in Equation (1) instead of the observed networking values. Adopting this two-step approach allows for the estimation of Equation (1) while controlling for the potential endogenity of N_j. Equations (2) presents the external networking equations to be estimated.

$$N_{ji} = \alpha_{jo} + \alpha_{j1} Employment_i + \alpha_{j2} IrishOwned_i + \alpha_{j3} Sector_i + \alpha_4 IF_i + \varepsilon_{2ji} \quad (2)$$

The variables $Employment_i$, $IrishOwned_i$ and $Sector_i$ are defined above. In addition, IF_i is a series of innovation hampering factors which may affect the likelihood of firms engaging in external networking. It is anticipated that each of the independent variables will affect the likelihood of a firm engaging in any of the knowledge sourcing activities outlined above (Roper et al. 2008; Doran and O'Leary 2011). As each dependent variable is binary, and as the decision to engage in different forms of knowledge sourcing may be related, a multivariate probit model is used to simultaneously estimate equation (2). It adds to the literature that treats the decisions to engage in different forms of external interaction as being interdependent (Roper et al. 2008; Doran and O'Leary 2011).

A key contribution of this paper is to determine whether there are marked differences between Irish and foreign owned firms. Recent Irish innovation literature has pointed to a dichotomous innovation system (Doran and O'Leary 2011; O'Leary 2015) and has found fundamentally different relationships between R&D spending and the probability of innovation by Irish and foreign-owned firms (Doran et al. 2013). We therefore implement likelihood-ratio tests to assess whether our empirical models can best be estimated on the full sample or whether it is necessary to estimate distinct models for Irish and foreign owned firms.

The likelihood ratio test is employed as we are using probit-models. The approach followed necessitates the estimation of a constrained and unconstrained model. In the constrained model we estimate equation (1) above constraining the coefficients for Irish and foreign-owned firms to be identical. In the unconstrained model we estimate equation (1) separately for Irish and foreign-owned firms, essentially allowing the coefficients to vary depending on the ownership of the firms. We then assess whether we get a statistically significant improvement in model fit when we compare the unconstrained model to the constrained model. If the fit is significantly improved this suggests that it is inappropriate to utilise the constrained model as the constraint of assuming that Irish and foreign owned firms are characterized by the same coefficients reduces the overall fit of the model, which in turn has implications for the accuracy of any interpretations of the results of the model. If the fit of the model is not significantly improved using the unconstrained models then the constrained equation is deemed to be most satisfactory as it is more parsimonious (Greene 2008).

The null hypothesis of the test is that the constrained model applies to each of the ownership types analysed and that there is parameter stability across ownership types. If we reject this null hypothesis the fit of the model is improved through the estimation of the unconstrained models.

VI. Results of Analysis

Table 2 presents the bivariate probit estimations of our innovation production functions for both Irish and foreign-owned firms. Following the approach outlined in Siedschlaga (2011) and Doran, Jordan and O'Leary (2012) we use the predicted values from our estimated external networking equations as instruments in our innovation product function. We also interact these predicted values with R&D to assess the nature of the relationship between these variables in the innovation production function.

Of particular interest are the results of our likelihood ratio test of parameter stability for Irish and foreign-owned firms. The first key result is our rejection of the null hypothesis that our constrained model (which groups Irish and foreign-owned firms together) provides an adequate fit for our innovation production function. The fit of our estimation is improved by considering Irish and foreign-owned firms separately. Constraining them to have the same coefficients reduces the accuracy of our estimates.

Given the results of our likelihood ratio test we consider Irish-owned and foreign-owned firms separately. In the first instance it should be noted that the coefficient on intramural R&D spending for both Irish and foreign-owned firms and for both product and process innovation is positive and significant. The coefficients for R&D being higher in both cases for product innovation relative to process innovation implies that R&D expenditure has the largest effect on the likelihood of product innovation. This confirms the importance of in-house creative effort and is a standard finding in the innovation literature (Roper et al. 2008; Doran et al. 2013).

The key coefficients of interest in this paper are the interaction terms between external interaction and internal R&D spending. We note that of a possible 16 relationships only six are statistically significant, and all of these significant results occur for Irish-owned firms. Similar to Doran, Jordan and O'Leary (2013) this suggests fundamental differences in the innovation activities of these firms. Foreign-owned firms are largely self-contained with the networking variables, both individually and interacted with R&D having no effect. There is no evidence supporting these innovation inputs being either complements or substitutes. This indicates that foreign-owned firms experience no benefit or loss to their likelihood of engaging in either product or process innovation from combining their networking and internal knowledge generation activities. Clearly, these relationships do not support the Cohen and Levinthsl (1990) hypothesis.

In contrast for Irish-owned firms networking appears to a certain degree to be important, albeit with mixed results. For these firms it is noticeable that those who network with public knowledge sources *and* undertake R&D are more likely to engage in both product and process innovation, indicating that these activities act as complements with the effects appearing to be stronger for process innovation. This lends some support to the Cohen and Levinthal (1990) hypothesis that what is important is a *combination* of creative effort associated with R&D and networking with these external agents. We can posit that in order for Irish-owned firms to exploit the knowledge gained from public networking for either product or process innovation, they must sufficiently develop their own absorptive capacity through the performance of R&D. Alternatively it may be that for firms to maximise the fruits of their R&D effort they must collaborate with public knowledge sources to finalise the development of the product or process or to bring the innovation to market. While our methodology allows us to ascertain that a

complementary effect is present, we cannot state with certainty which of these two posited relationships (if any) hold true.

It is interesting that for process innovation, the effect of public networking alone is negative.[ii] This suggests that for these firms it is important not only to network with public bodies, such as universities and public research institutes, but also to engage in R&D spending in order to ensure a positive effect on innovation. Thus, Irish-owned firms may turn to public knowledge sources, such as universities, in order to aid them in overcome shortcomings in their own R&D capability in relation to process innovation. Alternatively it may suggest that these firms may be unable to exploit the knowledge gained from public interaction without also undertaking internal R&D to, perhaps, enable them to develop the absorptive capacity to apply this knowledge within their firm.

For Irish-owned firms there is also a positive relationship between horizontal networking and engaging in R&D and the likelihood of engaging in process innovation. This also implies a complementary relationship, thereby supporting Cohen and Levinthal (1990). This positive effect may result from joint R&D projects with competitors in areas such as new technologies, supply chain innovations or new developments in other support activities. It is notable that there is no such effect for product innovation, perhaps because joint projects with competitors are less likely in this area.

It is interesting that for the remaining three of the six statistically significant relationships for Irish-owned firms the coefficients are negative, which is contrary to Cohen and Levinthal

(1990). For both product and process innovation Irish-owned firms which engage in backward networking *and* R&D activity are less likely to engage in these forms of innovation. This suggests that these knowledge inputs are not complements but substitutes for both product or process innovation. This finding may be a manifestation of the size and resource constraints experienced by Irish-owned firms, which are typically much smaller than their foreign owned counterparts. It may be that rather than engaging in R&D, which can be costly, firms instead interact with suppliers for knowledge to exploit as new products or processes (Freel 2003). This is supported by the finding that for backward networking alone, the coefficients for both product and process innovation are positive and significant. It suggests that firms may be able to exploit the knowledge gained from backwards interaction without the need to undertake intramural R&D. However, it should be noted that, especially for smaller firms, the absence of a formal R&D budget does not necessarily imply that these firms do not undertake creative effort to introduce new products and processes.[iii] Unfortunately, due to data limitations, we are not able to explore this point.

We also note a negative coefficient for Irish-owned firms for forward networking and engaging in R&D, in the context of process innovation. This also implies that these inputs are substitutes and suggests that firms gain more of a return by concentrating on either networking with customers or undertaking R&D. This may also be a manifestation of resource constraints experienced by Irish firms with firms substituting consumer interaction as a replacement for R&D ability.

In terms of relative effects it appears that the strongest complementary relationship is observed for public networks and R&D for process innovation, followed by horizontal networks and

R&D for process innovation and finally public networks and R&D for product innovation. The strongest substitution effects are forward networking and R&D for process innovation followed by backward networking and R&D for product and then process innovation. The stronger complementary/substitution effects for process innovation may suggest that it is external interaction which is important for driving process innovation while R&D by itself is the key determinant of product innovation for Irish-owned firms.

Table 2: Bivariate Probit Model of Innovation Production Function

	Irish		Non-Irish	
	Product	Process	Product	Process
Constant	-1.4602***	-0.9386***	-0.7056*	-0.6239
	(0.1856)	(0.1605)	(0.4120)	(0.4010)
Networking (N)				
Public	-2.8190	-4.7939**	-0.9436	1.0050
	(2.0214)	(1.8817)	(1.6862)	(1.6098)
Backward	4.7902*	4.5959*	1.6479	0.0940
	(2.7844)	(2.6129)	(2.3129)	(2.1518)
Forward	2.9908	2.3495	-3.0768	-0.7044
	(2.4643)	(2.3300)	(1.9688)	(1.8689)
Horizontal	-1.3718	-3.8917	3.0598	2.0225
	(3.0362)	(2.9229)	(2.0811)	(2.0453)
Research and Development (RD)	0.2612*	0.1876***	0.1975***	0.0912***
	(0.0260)	(0.0225)	(0.0428)	(0.0354)
Interaction Terms				
Public *and* RD	0.7813*	1.1660***	0.1908	-0.1139
	(0.4306)	(0.3758)	(0.2643)	(0.2245)
Backward *and* RD	-0.8808**	-0.6504**	-0.3788	0.3018
	(0.4099)	(0.3325)	(0.4224)	(0.3612)
Forward *and* RD	0.1815	-0.9402**	0.3710	0.0671
	(0.4460)	(0.3703)	(0.3580)	(0.3350)
Horizontal *and* RD	0.0605	0.8472*	-0.4042	-0.3799
	(0.5563)	(0.4782)	(0.4440)	(0.4137)
Sector[a]				
All Other Manufacturing	-0.0098	-0.2466	0.2401	0.2441
	(0.2076)	(0.1854)	(0.2173)	(0.2104)
Wholesale, Transport, Storage & Communication	0.0726	-0.1728*	0.1828	0.0417
	(0.1116)	(0.0976)	(0.2249)	(0.2119)
Financial Intermediation	-0.0606	-0.1930	-0.1244	0.0543
	(0.2585)	(0.2366)	(0.2421)	(0.2276)
Computer, Architecture & Engineering Services	-0.1070	-0.2991**	0.6462**	-0.0251
	(0.1501)	(0.1342)	(0.2560)	(0.2374)

Table 2: Bivariate Probit Model of Innovation Production Function con.

	Irish		Non-Irish	
	Product	Process	Product	Process
Firm Specific Factors				
Employment	-0.0107	0.1076**	0.1012	0.0258
	(0.0601)	(0.0541)	(0.0834)	(0.0786)
Factors which hamper Innovation				
market dominated by established enterprises	-0.1259***	-0.0419	0.0709	0.1376*
	(0.0477)	(0.0426)	(0.0822)	(0.0793)
uncertain demand for innovative goods or services	-0.0358	0.0405	-0.1598*	0.0367
	(0.0523)	(0.0473)	(0.0909)	(0.0874)
need to meet government regulations	0.1024**	0.0904**	-0.0422	-0.0184
	(0.0487)	(0.0437)	(0.0809)	(0.0776)
excessive perceived economic risks	0.0586	-0.1328***	0.0005	-0.1468*
	(0.0535)	(0.0471)	(0.0865)	(0.0827)
Obs		1659		522
Wald Chi2		562.69		176.93
Prob > Chi2		0.0000		0.0000
Log-Likelihood		-1531.97		-569.21

[a]High technology manufacturing is the reference category for the sector dummies.

***, ** and * indicate significance at the 99, 95 and 90 percent levels respectively.

VII. Conclusions and Implications

This paper focuses on analysing this complex relationship between internal knowledge generation and networking. Through the utilisation of interaction terms in a modified innovation production function, it tests the hypothesis associated with Cohen and Levinthal (1990) that the *interaction* of R&D effort and external networking is important in order to enhance a firm's probability of innovation. It controls for the potential endogeneity of the external networking variables by adopting a two-step procedure whereby these are estimated separately with predicted probabilities used as instruments in the estimated production functions. Given Ireland's strong reliance on foreign direct investment, the paper considers whether it is necessary to estimate innovation production functions separately for Irish and foreign-owned firms. The data used is from the Irish CIS: 2006-08.

The results justify separate analysis of Irish and foreign-owned firms. For Irish-owned firms there is mixed evidence in support of Cohen and Levinthal (1990), with three of the six significant interaction variables being positive as predicted but three being negative. It appears that public and horizontal networking act as complements to R&D spending, thereby suggesting a symbiotic relationship with these agents. However, it cannot be inferred that this relationship operates within Ireland as the location of the agents was not considered. This avenue could be explored in future work.

However, backward and forward networks are found to be substitutes for R&D spending, suggesting that Irish-owned firms should engage in either of these kinds of networking or R&D but not both. This result could reflect the small size of Irish-owned firms, where the average employment is 63 workers. As a result, the cost of R&D may force some firms to engage in networking. However, one should be careful in citing this as strong evidence rejecting Cohen and Levinthal (1990), as the measure used in the paper, which is formal R&D spending, may exclude creative innovative effort by small firms.

Contrary to Irish-owned firms, foreign-owned firms rely exclusively on intramural R&D for innovation as the external networking variables, both individually and when interacted with R&D, have no effect. This suggests that these businesses are largely autonomous in their innovation operations with little reliance on networking. While this unusual finding appears to refute Cohen and Levinthal (1990), it may be that Irish subsidiaries network intensively with head office, which in turn networks with external agents in other systems. As a result, foreign-owned firms in Ireland may get their absorptive capacity second-hand through head office or

indeed other subsidiaries within the corporation. This idea is worth further exploration, perhaps through case study analysis.

It is clear that while foreign-owned firms do innovate in Ireland, the country also offers these firms significant tax advantages associated with their innovation activities in Ireland through such inducements as low corporation tax, R&D tax credits and exemptions from income from patents and licences purchased within the European Economic Area. Indeed, these firms spend significant amounts of their total R&D budget on the purchase of licences and patents and get a very high return in terms of product innovation (Doran et al. 2013). However, overall these tax incentives may confound the investigation of the complex relationship between intramural R&D spending and external networking in terms of their effects on the probability of innovation by these firms. Given the dominance of foreign-owned firms in Ireland's enterprise base, it is important a better understanding is acquired on the innovation activities of these firms. In order to disentangle the effects of Ireland's tax regime, future work will need access to additional data on these firms.

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[i] The 3 year reference period 2006 to 2008 includes periods before and after the global financial crisis. This should not have a material effect on the results as, to our knowledge, there is no evidence from the international innovation literature on how firms innovate that the business cycle has a significant effect. We are also limited by the availability of the data, as the CIS is collected in 2008, covering the reference period 2006 to 2008. It considers the innovation behaviour of firms over this time period and it is not possible to identify the specific years, within this period, when activity occurred. Therefore, it is not possible for us to exclude any given year in order to restrict the analysis to the period before the crisis.

[ii] This echoes a result in Jordan and O'Leary (2008), that the more high-technology businesses network with universities the lower their probability of innovating.

[iii] See for example Jordan and O'Leary (2008) who find that what matters for innovation is whether or not the business conducts R&D rather than having a dedicated R&D department.