Embracing a systems perspective of innovation – Evidence from Ireland on the use of innovation links, 1991 to 2002

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Abstract

Conceptual perspectives on the innovation process have changed dramatically in the past decade from a linear model of the innovation process to one based on an evolutionary or systems perspective of innovation. Innovation networks are now perceived as critical with interaction and co-operation between firms and other organisations driving innovation. Drawing on longitudinal plant-level survey data in Ireland from 1994 to 2002 this paper examines if evidence exists to support the conceptual perspective that innovation links have increased in recent years. In particular, the intensity of innovation links are examined with differences in the use of innovation links by firm size, sector, ownership or location over the period also being highlighted. These findings are considered in terms of the underlying innovation system and public policy initiatives to promote technology transfer and networking as implemented throughout Ireland from 1991 to 2002.

Keywords: Innovation; Linkages; SMEs; Innovation policy

1. Introduction

In recent decades, linkages between industry and science and the diffusion of knowledge within national innovation systems are emerging as a primary focus for innovation policy (OECD, 2002). The rationale behind this focus is the awareness that Research and Development (R&D) is becoming increasingly complex, the uncertainty and costs of undertaking innovation are increasing and innovation cycles are being compressed (Contractor and Lorange, 1988). Firms that engage in innovation linkages, whether with the marketplace or other external sources of technological expertise, derive significant benefits to their innovation activities and are therefore more likely to be successful innovators (Rothwell, 1991).

Conceptually, views of the innovation process have changed over the last few decades from the traditional linear model supporting the 'technology push' and 'demand pull' approaches to business innovation, towards a more systemic or evolutionary model of innovation (Nelson and Winter, 1982). This systemic perspective is characterised by intense interactions between businesses (Edquist, 1997) and other organisations as represented by Rothwell's (1992) fifth generation innovation process. These linkages include strong horizontal linkages such as joint ventures, collaborative research groupings etc. as well as strong vertical linkages with leading edge customers and suppliers in the development of future leading-edge innovation. Both the public and private sector have key roles to play in the innovation system. Governments play an important role through their policy initiatives to strengthen firm's R&D activities and regional governments are increasingly aware of the potential of linkages between the various actors in the regional innovation system as an essential part of this goal.

Using empirical data this paper will determine if there has been increase in innovation linkages by firms in Ireland between 1994 and 2001, representing a move from closed to open innovation. It will analyse the determinants of companies engaging in innovations by their plant characteristics, innovation capability, innovation activity and human resource capability. It will also seek to determine if government policy initiatives have impacted companies' decisions to undertake innovation linkages by looking at the effects of government assistance. The performance of companies

engaging in innovation linkages will also be analysed to see if they have higher sales and growth compared to companies who don't partake in an innovation linkage.

The remainder of the paper is organised as follows. Section 2 describes the conceptual framework which is based on the resource based view of the firm. This provides an understanding of why firms engage in external innovation linkages and the connection between these linkages and a firms' R&D and innovative outputs. Section 3 discusses how the policy environment a firm operates in can influence a firm's innovation outputs. Section 4 describes the data sources use in the analysis and section 5 outlines the empirical results. The empirical analysis covers Northern Ireland and the Republic of Ireland and will take account of differences in these regional contexts.

2. Conceptual Framework

Firms which innovate successfully are generally well connected to the marketplace and to external sources of technological expertise (Rothwell, 1991). But what are the benefits to innovation activity that are derived from innovation linkages? Von Hippel (1994) argues that the ability to innovate calls for access to 'invisible factors' such as 'tacit knowledge' or 'sticky information'. These factors are hard to come by, particularly in SME's, and are therefore most easily accessed through innovation linkages and networks.

Recent research suggests that over the past decade firms have increasingly outsourced part or all of their R&D activities to other firms or institutions (e.g. Hagedoorn, 2002; Harrigan, 1986). Chesbrough (2003) has termed this growing tendency to utilise external sources of knowledge as 'open innovation', proposing that ideas can flow out of the firm to find better sites for their commercialisation and also flow into the firm as new offerings and new business models. This approach stands in stark contrast to earlier tendencies by companies to rely solely on in-house R&D capabilities, a situation which Chesbrough (2003) refers to as 'closed innovation'.

Explanations for this overall growth in R&D and innovation partnerships are generally related to the motives that 'force' companies to collaborate on R&D. The most significant of these has been industrial and technological changes in the 1980s and 1990s which have led to increased complexity of scientific and technological development, higher uncertainty surrounding R&D, increasing costs of R&D projects, and shortened innovation cycles (Contractor and Lorange, 1988, Katz and Martin, 1997). A dependence on internal resources within a firm may therefore constrain major innovation projects (Kanter, 1994) particularly in capital and R&D intensive industries, such as the telecoms sector, where the cost of single, large R&D projects are beyond the reach of many companies (Hagedoorn, 1993). On the other hand, this also suggests that innovation linkages for cost-minimization purposes may be less significant in low-R&D intensive sectors.

Studies of collaboration across industry show the high number of them devoted to technological issues (Dodgson, 1993). Mowery (1998) suggests that technology is increasingly the focus of collaborations and that technological collaboration is appearing in a wider range of industrial sectors and firms. Harrigan (1986) sees collaboration as a feature of the high technology industry and the development and early use of new technologies. Dodgson (1993) details the following studies of individual industries and technologies which show a high level of collaboration: information technology (Freeman, 1991); biotechnology (Pisano, Shan and Teece, 1988); automobiles (Womack, 1988); aircraft (Mowery, 1987); telecommunications (Pisano, Russo and Teece, 1988); integrated circuits (Steinmuller, 1988); robotics (Klepper, 1988); computer systems (Saxenian, 1991), Semiconductors (Hobday, 1991); food (Senker, 1986) and steel (Lynn, 1988).

Firms may also enter into collaborative arrangements for strategic purposes, for example companies may decide to enter into R&D partnerships or linkages that are not related to their core activities, while keeping their main R&D activities within their own domain (Teece, 1987). The strategic intent of R&D partnerships is also apparent in those cases where companies jointly perform R&D in new, high-risk areas of which the future importance for their technological capabilities remains unclear for a considerable period of time. Most studies on R&D partnerships or similar forms of alliances stress a variety of strategic and cost-economising motives for these

partnerships (Das et al. 2000; Hagedoorn et al. 2000; Mowery, 1998). It is important to realise there is a dynamic aspect to all of this as the motives of a company can change over time due to both developments in the company itself, its environment and changes with the partnership (Harrigan, 1986).

In recent years there has been an expanding empirical literature on the determinants of innovation linkages (Kleinknecht and Reijnen, 1992; Fritsch and Lukas, 2001; Tether 2002; Belderbos et al. 2004). The main determinants considered in these empirical studies are firm size and R&D intensity. For example, Fritsch and Lukas (2001) confirm that firm size and R&D increase the propensity to cooperate among German manufacturing firms but find that the assignment within the firm of 'gatekeepers' monitoring and transmitting external information to relevant internal departments has an additional positive impact. This empirical research takes account of the simultaneous relationship between R&D cooperation and in-house R&D activities. Kleinknecht & van Reijnen (1992) find that if a firm has its own R&D department the probability of the firm collaborating with partners increases. Further Veugelers (1997) finds that Belgian firms spending more on internal R&D have a significantly higher probability of cooperation in R&D.

The type of R&D being performed may also affect the likelihood of innovation linkages. Tether (2002) in his study of UK innovating firms finds that R&D cooperation is mostly associated with firms that are pursuing radical innovations rather then incremental innovations. Belderbos et al. (2004) state that cooperation with a particular partner is more likely to be chosen if that partner is considered an important source of knowledge for the innovation process, while knowledge sourced from universities and research institutes positively impacts all types of cooperation. The authors suggest that R&D cooperation with universities is more likely to be chosen by R&D intensive firms in sectors that exhibit faster technological and product development. In addition, other authors suggest cooperation with universities and research institutes is generally more aimed at innovations that may open up entire new markets or market segments (Tether, 2002; Monjon and Waelbroeck, 2003).

Link and Bauer (1987) have shown a positive correlation between cooperative R&D conducted by a firm, the firm's market share, and the productivity of the firm's in-

house R&D. The latter result suggests that participation in a research partnership increases the absorptive capacity of firms with regard to their R&D activity (Hagedoorn et al. 2000). Cohen and Levinthal (1990, 128) define absorptive capacity as "…the ability of a firm to recognise the value of new, external information, assimilate it and apply it to commercial ends." Cohen and Levinthal (1990) chose R&D expenditure as the main variable of absorptive capacity. The authors also emphasised that absorptive capacity "depends on the transfer of knowledge across and within sub units that might be removed from the original point of entry" (1990, 131).

From a resource based perspective innovation linkages may allow firms to maximise firm value through effectively combining the resources of partners to exploit complementarities (Kogut, 1988; Hagedoorn 1993; Das and Teng 2000; Hagedoorn, Link and Vonortas 2000). These firm-specific heterogeneous resources can be classified into three general categories: (i) financial capital resources, (ii) human resources and capabilities and (iii) organisational resources and capabilities (Barney, 1991). As such, each firm is therefore a unique bundle of tangible and intangible resources and capabilities (Wernerfelt, 1984) with firms acquiring, developing and expanding their resource bundles over time[1].

From a resource based perspective, external linkages by firms is perceived as a device that combines characteristics of markets with intra firm organisations and thereby enables firms to gain access to these capabilities (Kogut, 1988; Hamel, 1991). A firm's broad based skills and capabilities (i.e. resources) are often referred to as core competencies (Prahalad and Hamel, 1990). Prahalad and Hamel point to cooperative relationships as one means of internalizing core competencies (i.e. learning) and enhancing competitiveness. These relationships can then be used to acquire tacit knowledge from the partner (Kogut, 1988). Cohen and Levinthal (1989) assert that innovative capabilities depend on the ability to exploit external knowledge and also on in-house R&D efforts. The authors add that a firm's ability to develop an absorptive capacity depends heavily on investments made during previous periods.

[1] This proposal of looking at firms as a bundle of resources has its roots in the seminal work of Penrose (1959), Nelson and Winter (1982), and has been developed in the work by Wernerfelt (1984) and Teece et al. (1997) among others.

These initial investments allow them to make better technical choices and better exploit opportunities.

Drawing on the existing literature, this paper examines four key questions:

1. To what extent has innovation policy encouraged the move from linear to more systemic innovation system?
2. Is there evidence to support the view that there has been a move from closed to open innovation as demonstrated through greater use by firms' of external innovation linkages?
3. Is the likelihood of firms engaging in external innovation linkages a reflection of their absortive capacity as assessed from a resource based perspective?
4. Is there evidence to suggest that engaging in external innovation links over time is positively associated with innovation output and performance?

3. Policy environment

Innovation and technology development are increasingly seen as the result of a complex set of relationships among actors in an innovation system, which includes enterprises, universities and government organisations. Policy initiatives may be particularly important in strengthening firm's R&D activities with publicly funded technology programmes used to promote inter-organisational technological linkages and economic development (Rothwell and Dodgson, 1992).

Both Northern Ireland and the Republic of Ireland have low levels of R&D investment (see O'Malley et. al. 2006). For example, in 2001 the Republic of Ireland's business expenditure on R&D (BERD) was only 0.95% of GNP[2], compared with the EU average of 1.21% of GDP and the OECD average of 1.56% of GDP (OECD, 2002). Northern Ireland's BERD is less than the Republic of Ireland, representing only 0.82% of GDP. A wide range of policies and activities designed to stimulate R&D and innovation, technology adoption and design have been introduced in both regions. Although, Roper (1998) suggests that less that 2% of the Industrial

[2] GNP is a more appropriate measure than GDP due to the scale of transfer payments from the large foreign-owned sector.

development budget in Ireland is targeted at building innovation linkages or collaboration between firms.

The Department of Trade and Investment's, Innovation Report (DTI, 2003), outlined the importance of networking actives which are 'vital for firms to learn about the benefits of innovation and identify opportunities from collaborations and stimulate them to take action" (2003, 109). In Northern Ireland's the regional innovation strategy 'Think, Create, Innovate' (Department of Enterprise, Trade and Investment, 1999, 34) outlined the importance of innovation links to firms outlining that "companies need to form strategic alliances and collaborative partnerships to maximise R&D and innovation opportunities." The document also stressed the importance of more systematic engagement with universities by businesses, in particular SMEs, to assist R&D and innovation activities. In Northern Ireland, government assistance to promote R&D has taken a two-track approach in terms of both direct financial incentives to promote R&D and innovation, as well as wider support measures to create a socially conducive environment for R&D and innovation. These non-innovation support mechanisms play an important role in assisting companies to engage in innovation linkages. Examples of such programmes are the Networking Programme, the Knowledge Transfer Partnership and the LINK Collaborative Research scheme. The Networking Programme provides small grants to assist with travel and network development as part of product development activities and in support of EU collaborative programmes. The Knowledge Transfer Partnership (KTP) (formerly known as the Teaching Company Scheme) is a well-established UK-wide scheme supporting technology transfer and university-industry collaboration through graduate placements. The LINK Collaborative Research scheme is the main government mechanism for promoting collaboration in pre-commercial research between business and the research base.

Similar to Northern Ireland, the Government in the Republic of Ireland understands that there is a need to increase business investment in R&D. It is estimated that BERD will need to increase to €2,540 million by 2010 to meet the EU 3% R&D Target (Interdepartmental Committee on Science and Technology, 2003). Forfás is the national policy and advisory board for enterprise, trade, science, technology and innovation. In 1993 a Government report entitled A Strategy for Competitiveness,

Growth and Employment stated that "innovation must lie at the heart of future policy for Irish Industry" (NESC, 1993, 260-261). The report continued that "this does not necessarily imply the capacity of every firm to carry out in-house R&D, but it does require firms to belong to networks where R&D in being done" (NESC, 1993, 261). This statement illustrated the Irish government's policy shift from a focus on business capacity expansion to a greater emphasis on business capability expansion.

In Ireland, low corporate tax rates are a national economic policy aim and have provided the Industrial Development Authority (IDA) with a significant competitive advantage in attracting foreign multi-national manufacturing companies to Ireland. However concurrent efforts to increase BERD levels have been hampered by that same corporate tax regime and research by Forfás (1998) has shown that decisions to locate R&D functions in Ireland, especially by multinational enterprise, are adversely affected by low tax rates because firms prefer to incur R&D costs where they can be offset against higher taxes (OECD, 2002).

The key role for science, technology and innovation policy was signalled in the National Development Plan 2000-2006 which allocated €2.5 billion for Research, Technology Development and Innovation (RTDI). Incentives for companies to carry out R&D in Ireland have typically focused on providing grant aid to cover R&D staff costs primarily but also with some level of contribution to overheads, materials, externally-sourced consulting and capital terms. In a recent Irish government report entitled 'Ahead of the Curve' (2004) a number of recommendations were made to increase innovation links and networks in Ireland. The report recommended the government allocate 20 million euro per annum for firms to "support the creation of enterprise–led networks to foster collaboration in defined areas of activity" (ESG, 2004, P. 73)

A number of programmes exist to support innovation linkages in Irish industry. The Innovation Partnerships Programme is aimed at stimulating product and processes development for industry through collaboration with the higher education sector. In addition to national schemes, there are a number of European Union programmes and grants which can benefit companies such as the CRAFT programme which allows small companies to out-source research and EUREAKA which promotes

collaboration between R&D entities across the EU. The Advanced Technology Research Programme (previously the Programmes in Advanced Technologies) are partnerships between government agencies, industry and the Universities. The programme has two main objectives; firstly, to help industry to access new technology in order to improve the competitiveness of existing production and also to move into new higher value areas and secondly, to attract overseas and domestic investment in high technology areas and lead to the establishment of new technology based start-up companies (Forfás, 2002).

4. Data

Analysis is based on plant-level data from a panel survey of innovation in the manufacturing sector in Ireland. The data is taken from a postal survey of plants' Innovation Activity (called the Irish Innovation Panel) conducted at three periods, 1994; 1997; 2000. Samples were drawn from lists of businesses from Forfás in the Republic of Ireland and from the IDBR in Northern Ireland. The target population was manufacturing plants with 10 or more employees. Surveys were plant rather than company based and structured samples in each region were stratified by industrial sector and plant size. The data analysed in this research is drawn from this panel data and only includes those companies responding to all three postal surveys conducted between 1992 and 2002, which amounted to 148 plants.

This innovation survey gathered data on firm R&D expenditures and on the innovation inputs as well as R&D related performances and other innovation outputs. The survey covers the following topics: expenditure on activities related to product and process innovation; outputs and sales of new or improved products; sources of information relevant to innovation; technology transfer and acquisition; R&D performance and technological collaboration; and perceptions of factors promoting or hampering innovation. Table 1 describes the sample characteristics.

Table 1: Sample Characteristics

Main Characteristics

Region of company	
Northern Ireland	50%
Republic of Ireland	50%
Ownership	
Indigenous	80.3%
Foreign	19.7%
Size of company	
Large (employee number >250)	6.8%
Medium (employee number 50-250)	36.5%
Small (employee number <50)	56.8%
	100%
Industrial sectors	
Food, drink and tobacco	12.8%
Textiles and clothing	8.8%
Wood, paper and printing	3.4%
Chemicals	7.4%
Metals and metal fabrication	8.8%
Mechanical engineering	5.4%
Electrical and optical equipment	6.1%
Transport equipment	2.7%
Other manufacturing	18.9%
	100%

Manufacturing plants that responded to the survey provided information on their R&D activities and their linkages with other firms or research organisations. Firstly, the types of linkages the plants engaged in will be analysed on an all Ireland perspective and then by region, Northern Ireland and the Republic of Ireland.

The use of horizontal and vertical links throughout the three periods will then be analysed. Horizontal links are linkages the plant has with other group companies; clients or customers; suppliers. Vertical links are those with competitors; joint ventures; consultants; government labs; university labs or industry labs. A measure of the intensity of horizontal and vertical links is calculated for each wave by measuring the number of links the firm has divided by the maximum number of links possible. For example for vertical links the company's number of vertical links is divided by 3 (other group companies, suppliers and customers). The proportion of firms with innovation linkages will then be looked at in relation to firm size, ownership and sector.

Hierarchical cluster analysis will be utilised to analyse the persistency of company innovation linkages throughout the three waves. Based on the typology of this paper and the sample size it was determined that three clusters will be analysed: (1)

companies with persistent innovation links, i.e. firms with links throughout all three periods; (2) companies with transitory innovation links, i.e. companies with links in one out of the three periods and (3) companies with no innovation links. Using the First period as a base line, the results from the cluster analysis will provide details on plant characteristics and performance, human resource capability, innovation capability, innovation activity and government assistance and their effect on the persistency of innovation links. Cluster analysis will also be utilised to look at the effect of Innovation links on business success. Changes in performance, human resource capability, innovation capability and innovation activity will be analysed with periods 2 and 4.

5. Empirical Analysis

5.1 Pattern of Innovation Linkages in Ireland

Firstly, to understand the pattern of innovation linkages in Ireland table 2a details the proportion of manufacturing plants with innovation links over the three periods. The types of linkages analysed were: linkages with other group companies; clients or customers; suppliers; competitors; joint ventures; consultants; government labs; university labs or industry labs.

Table 2a
Proportion of Manufacturing Plants with Innovation Links in Ireland 1994-2002

	1994-96	**1997-99**	**2000-02**
Innovation Links	33.1	40.5	43.2
Other Group Companies	13.8	20	22.4
Clients/Customers	20.7	24.1	25.9
Suppliers	18.6	25.5	28.6
Competitors	4.1	4.8	5.4
Joint Ventures	5.5	9.7	12.2
Consultants	11.7	18.6	21.8
Government Labs	4.1	7.6	6.8
University Labs	11	13.8	17
Industry Labs	5.5	4.1	5.4

The proportion of manufacturing plants with innovation links of all types in Ireland increased in all three periods showing a more ‘open’ innovation environment.

Horizontal innovation links with other group companies, clients/customers and suppliers are the most common type of innovation throughout all three periods. The most dramatic increase throughout the period was in the use of consultants, with the proportion of firms utilising consultants for innovation nearly doubling from 11.7% to 21.8% between the first and last period. Government labs and Industry labs were the only innovation link to suffer a decline in their use by firms with a slight decline between periods 2 and 3 of 0.8% and 1.3%, respectively. University labs are an increasingly important source of innovation for firms with a 6% increase in the proportion of firms using them as an innovation linkage between 1994 and 2002.

Table 2b
Proportion of Manufacturing Plants with Innovation Links in Northern Ireland and the Republic of Ireland, 1994-2002

	1994-NI	1996 ROI		1997-NI	1999 ROI		2000-NI	2002 ROI	
Innovation Links	24.3	41.9	*t=-2.296***	31.1	50	*t=-2.372***	35.1	51.4	*t=-2.005***
Other Group Co.s	5.6	21.9	*t=-2.93****	12.5	27.4	*t=-2.271***	20.3	24.7	*t=-0.634*
Clients/Customers	13.9	27.4	*t=-2.026***	19.4	28.8	*t=-1.312*	21.6	30.1	*t=-1.176*
Suppliers	13.9	23.3	*t=-1.456*	19.4	31.5	*t=-1.672**	21.6	35.6	*t=-1.886**
Competitors	2.8	5.5	*t=-0.815*	1.4	8.2	*t=-1.939**	4.1	6.8	*t=-0.742*
Joint Ventures	4.2	6.8	*t=-0.705*	5.6	13.7	*t=-1.669**	12.2	12.3	*t=-0.031*
Consultants	8.3	15.1	*t=-1.261*	8.3	28.8	*t=-3.26****	17.6	26	*t=-1.240*
Government Labs	5.6	2.7	*t=-0.846*	4.2	11	*t=-1.551*	5.4	8.2	*t=-0.673*
University Labs	5.6	16.4	*t=-2.115***	6.9	20.5	*t=-2.413***	13.5	20.5	*t=-1.131*
Industry Labs	4.2	6.8	*t=-0.705*	1.4	6.8	*t=-1.662*	5.4	5.5	*t=-0.020*

Significance levels: * p<0.10; **p<0.05; ***p<0.01

Looking at the pattern of innovation links from a regional perspective shows significant differences between the two regions. The Republic of Ireland (ROI) had a statistically significant higher proportion of firms with innovation links over the three periods compared to Northern Ireland (NI). ROI had a higher proportion of plants than NI in every type of innovation linkage (apart from Government labs in the first period). Over the three periods the percentage differential of the proportion of firms with innovation links is decreasing between the two regions, meaning that NI firms are catching up with the ROI firms.

Table 3
Use of Horizontal and Vertical Links in NI and ROI

	1994-1996			1997-1999			2000-2002		
	NI	ROI		NI	ROI		NI	ROI	
Vertical Links	20.3	39.2	t=-2.556**	29.7	43.2	t=-1.713	33.8	45.9	t=-1.512
Horizontal Links	14.9	28.4	t=-2.010**	14.9	39.2	t=-3.441**	21.6	37.8	t=-2.178**
Horizontal & Vertical Links	10.8	25.7	t=-2.370**	13.5	32.4	t=-2.789**	20.3	32.4	t=-1.684

Significance levels: * p<0.10; **p<0.05; ***p<0.01

5.2 Use of Horizontal and Vertical Linkages

Table 3 illustrates the use of use of horizontal and vertical Linkages by firms. Horizontal links are linkages the plant has with other group companies; clients or customers; suppliers. Vertical links are those with competitors; joint ventures; consultants; government labs; university labs or industry labs. Firms in the ROI have consistently had a greater usage of vertical and horizontal links across all three time periods in comparison to NI firms. The results indicate that greater proportion of firms in both ROI and NI use horizontal links than vertical links with the proportion of manufacturing firms utilising vertical links in the two regions increasing throughout all three periods. The picture was different though in the case of horizontal links where the proportion of manufacturing firms engaging in horizontal innovation links increased overall between periods 1 and 3, with a slight fall for ROI firms between periods 2 and 3. A much higher proportion (37.8%) of ROI firms utilise horizontal innovation links compared to only 21.6% in NI. As regards firms having both horizontal and vertical links simultaneously, yet again a greater proportion of ROI firms (32.4%) in period 3 use them compared to only 20.3% of NI firms. Although over the 3 periods the proportion of NI firms using both horizontal and vertical innovation links has nearly doubled from 10.8% to 20.3%.

Table 4a

Intensity of Horizontal and Vertical Links, ROI and NI (mean values)

	1994-1996		1997-1999		2000-2002	
	NI	ROI	NI	ROI	NI	ROI

Vertical Links	0.11	0.24	*t=-2.707***	0.17	0.29	*t=-2.241***	0.21	0.3	*t=-1.463*
Horizontal Links	0.05.	0.09	*t=-1.568*	0.05	0.15	*t=-3.485***	0.1	0.13	*t=-1.003*

Significance levels: * p<0.10; **p<0.05; ***p<0.01

Table 4a shows the intensity of horizontal and vertical links. Vertical links (i.e. links with another company plant, supplier or customer) have a greater intensity than horizontal links in both NI and ROI. The intensity of vertical links for both NI and ROI increased throughout the 3 periods, although ROI companies have a much greater intensity of vertical and horizontal links than NI companies.

Table 4b
Intensity of Horizontal and Vertical Links, ROI and NI (mean values of firms with links)

	1994-NI	**1996 ROI**		**1997-NI**	**1999 ROI**		**2000-NI**	**2001 ROI**	
Vertical Links	0.44	0.57	*t*=-1.424	0.54	0.58	*t*=-0.533	0.6	0.58	*t*=0.299
Horizontal Links	0.20	0.21	*t*=-0.104	0.14	0.29	*t*=-2.716**	0.28	0.25	*t*=0.332

Significance levels: * p<0.10; **p<0.05; ***p<0.01

Table 4b illustrates the intensity of horizontal and vertical links for companies for companies that engaged innovation links in each period. As before, vertical links have a greater intensity than horizontal links in both NI and ROI and ROI companies have a much greater intensity of vertical and horizontal links than NI companies.

Table 5
Number of Links NI/ROI

	1994-NI	**1996 ROI**	**1997-NI**	**1999 ROI**	**2000 NI**	**2002 ROI**
Mean Number of links per Firm	0.64	1.26	0.79	1.78	1.22	1.7

The average number of links per firm in ROI was twice that of NI's, in periods 1 and 2. In NI the average number of links per firm increased over the three periods, doubling over this time. Therefore, the results indicate that individual firms increased

the number of links they had with other companies or institutions between 1994 and 2002.

Table 6
Innovation Links and Firm Size, Ownership and Sector

	1994-NI	1996 ROI		1997-NI	1999 ROI		2000-NI	2002 ROI	
Size									
<50	16.7	32.3	*t=-1.541*	22.9	32.3	*t=-0.899*	22.9	29	*t=-0.593*
50-250	33.3	47.1	*t=-1.005*	47.6	70.6	*t=-1.677*	52.4	64.7	*t=-0.885*
250+	66.7	80	*t=-0.343*	66.7	40	*t=0.645*	100	100	
Ownership									
Indigenous	21	29.5	*t=-0.987*	29	38.6	*t=-1.019*	33.9	40.9	*t=-0.730*
Foreign	20	66.7	*t=-2.064**	60	66.7	*t=-0.250*	20	71.4	*t=-2.295**
Sector									
Food, Drink and Tobacco	36.4	75	*t=-1.729*	36.4	75	*t=-1.729*	36.4	75	*t=-1.729*
Textiles and Clothing	22.8	25	*t=-0.096*	33.3	50	*t=-0.500*	22.2	25	*t=-0.096*
Wood and Related Products	0	33.3	*t=-1.000*	100	0		50	0	*t=1.000*
Paper and Printing	20	16.7	*t=0.128*	40	50	*t=-0.302*	40	16.7	*t=0.788*
Chemicals	0	50	*t=-2.646*	50	8705	*t=-0.728*	50	75	*t=-0.425*
Metals & Metal Fabrication	0	40	*t=-2.449*	33.3	40	*t=-0.180*	33.3	40	*t=-0.180*
Mechanical Engineering	33.3	40	*t=-0.161*	33.3	60	*t=-0.645*	66.7	60	*t=0.161*
Electrical & Optical Equip	50	42.9	*t=0.132*	0	57.1	*t=-2.828***	50	85.7	*t=-0.687*
Transport Equipment	0	100		0	100		0	100	
Other Manufacturing	23.5	36.4	*t=-0.692*	23.5	36.4	*t=-0.692*	29.4	45.5	*t=-0.825*

Significance levels: * p<0.10; **p<0.05; ***p<0.01

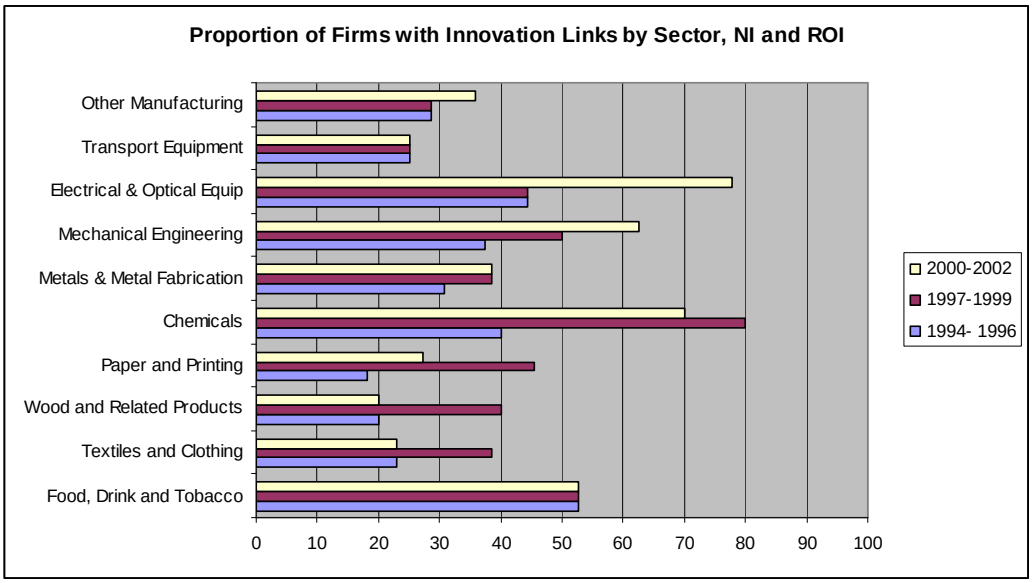
Innovation Links and Firm Size

Larger firms are more likely to have innovation links, both horizontally and vertically than smaller firms in both NI and ROI. In all three periods firms with 50-250 employees had more than double the innovation links of with firms with less than 50 employees. On average when looking at the difference between the two regions ROI firms had more innovation links in large and small firms compared with NI, although the difference between the means is not statistically significant. Similar results were found by Fritsch and Lukas (2001) in their study of German manufacturing firms were firm size increased the propensity of firms to cooperate with external partners.

Innovation Links and Ownership

On average over all three periods a greater proportion of foreign firms have innovations in comparison to indigenous firms. The picture is quite different when we compare ROI and NI. In ROI over all three periods, a much higher proportion offoreign firms have innovation links with other firms. These results concur with Love and Roper's study (2001) of networks in Germany, the UK and Ireland, where external ownership was positively associated with greater external networks and linkages, particularly in the UK.

Table 7
Innovation Links by Sector



Innovation Links by Sector

On average as regards sectoral differences ROI firms had more innovation links in all sectors than NI firms. There is a particularly strong showing of innovation links in food, drink and tobacco, chemicals, electrical and optical engineering and mechanical engineering. Food, drink and tobacco companies had a relatively high proportion of innovation links in all three periods. Senker (1986) in his study of technological cooperation between manufacturers and retailers in the food industry also found high level of collaboration. Textiles and Clothing, transport equipment and wood and wood related products and paper and printing had the lowest proportion of firms with innovation links.

When looking at changes over the 3 periods, chemicals, electrical and optical engineering and mechanical engineering sectors had the largest increases. The proportion of firms with innovation links in the chemicals sector increased from 40% in period 1 to 70% in period 3. Similar increases occurred in the electrical and optical engineering sector with 44.4% of plants in period 1 with innovation links rising to 77.8% of firms in period 3. The proportion of firms with innovation links in the mechanical engineering sector increased from 37.5% in period 1 to 62.5% in period 3. These results are in agreement with Rothwell's study of external networking in European manufacturing plants (Rothwell, 1991) were he argued that companies operating in traditional sectors have lower technological requirements than those operating in other industrial sectors.

5.4 Cluster Analysis

Using the persistency of company linkages in each period, hierarchical cluster analysis was carried out. Based on the typology of this paper and the sample size, it was determined that the number of the clusters was three.

Table 8
Clusters of Firms with Innovation Links

	Firms	%
Persistent Innovation Links	50	33.8%
Transitory Innovation Links	29	19.6%
No Persistent Innovation Links	69	46.6%
Total	148	100%

Out of the 148 companies in the database, three main clusters can be distinguished: Firstly, Companies with persistent innovation links. 50 companies are in this category with these companies having innovation links with other firms throughout the three periods, representing 33.8% of companies in the database. The second category is companies with transitory innovation Links. Companies in this category had innovation links in one out of the three time periods, with 29 companies or 19.6% of the sample in this category. The last category consists of companies with no innovation links. These are companies who pursued no innovation links with other

firms throughout all three periods of the survey. The majority of companies are in this category, 67 firms or 46.6% of firms.

Table 9
Innovation Links and Plant Capability and Performance

	Persistent Innovation Links	Transitory Innovation Links	No Innovation Links	Significance tests
Plant Characteristics				
Turnover 1993	15,102	21,416	9,460	*t=0.705*
Employment 1993	114.02	97	39.25	*t=4.100***
Performance				
Sales growth since 1993	35.18	51.52	25.58	*t=0.877*
Employment Growth since 1993 %	13.27	30.79	9.52	*t=0.793*
% of Sales outside British Isles	31.67	22.69	12.47	*t=3.095***
Human Resource Capability				
% of Workforce with Degrees	9.98	8.29	5.49	*t=2.522***
Innovation Capability				
Number working on R&D	3.67	1.60	0.44	*t=2.003*
R&D Expenditure 1993 (000)	250.33	52.11	11.27	*t=2.007*
R&D Done in Plant (%)	60	69	31.8	X^2*=14.844***
R&D Expenditure per employee	1.35	0.89	0.26	*t=2.433***
R&D Dept in Plant (% of firms)	29 %	24%	7%	X^2*=9.518***
Innovation Activity				
Product Innovator (% of firms)	72	83	45	X^2*=15.799***
Number of New/Improved products	11.78	3.40	4.74	*t=1.538*
Processes Innovator (% of firms)	62	62	33	X^2*=12.365***
Government Assistance				
Gov. Assistance Product Dev. (%)	37	31	11	X^2*=11.451***
Gov. Assistance Process Dev. (%)	24	21	9	X^2*=5.055*
Gov. Assistance Exporting (%)	28.6	44.8	15.4	X^2*=7.380***
Gov. Assistance Non-Specific R&D (%)	18.4	13.8	3.1	X^2*=9.347***

Significance levels: * p<0.10; ***p*<0.05; ***p<0.01

As previously discussed a firm's innovative capabilities depend on the ability of the firm to exploit external knowledge and on in house R&D efforts (Cohen and Levinthal, 1989). Internal factors such as firm size turnover and employment; percentage of workforce with degrees; number for people working on R&D; R&D expenditure and government assistance are expected to effect the firms ability to exploit external knowledge. The results from the cluster analysis will be analysed by plant characteristics, performance, human resource capability, innovation capability, innovation activity and government assistance.

Plant Characteristics

According to the results a firm's average turnover is higher if a firm has persistent or transitory links compared with companies with no links. As regards employment, firms with persistent innovation links employ nearly 3 times more people than those with no innovation links. There exists a statistically significant difference between companies with persistent innovation links and those with no innovation links (p=0.000). Therefore, the results indicate that companies with higher employment levels are more likely to have persistent innovation links.

Performance

In general the results indicate that companies with persistent or transitory innovation links have a higher sales growth compared to companies with no innovation links over the three time periods. The impact of employment growth on the persistency of innovation links is not very marked. Companies with no innovation links and persistent innovation links had similar employment growth, 13.27% and 9.52% respectively. Companies with transitory innovation links had employment growth of 30.79%.

Firms with a higher percentage of sales outside the British Isles are more likely to have persistent or transitory innovation links. On average firms with persistent innovation links have 31.67% of sales outside the British Isles companies with only 12.47% for those with no innovation links. Therefore, the results indicate that exporting firms are more likely to have transitory or persistent innovation links. Link and Bauer (1987) have shown a positive correlation between cooperative R&D conducted by a firm, the firm's market share, and the productivity of the firm's in-house R&D. The latter result suggests that participation in a research partnership increases the absorptive capacity of firms with regard to their R&D activity (Hagedoorn et al. 2000). Cohen and Levinthal (1990, P.128) define absorptive capacity as "…the ability of a firm to recognise the value of new, external information, assimilate it and apply it to commercial ends." Cohen and Levinthal (1990) chose R&D expenditure as the main variable of absorptive capacity. The authors also emphasised that absorptive capacity "depends on the transfer of knowledge across and within sub units that might be removed from the original point of entry" (P.131).

Knowledge stocks and therefore the absorptive capacity of the firm may differ across organisational sub units.

Human Resource Capability

The importance of the percentage of workforce with degrees is evident from the results with a significantly positive association between the presence of employees with university degrees and the persistency of innovation links. As regards the percentage of staff with degrees, firms with persistent innovation links and transitory innovation links employ more people with degrees than those with no innovation links. Firms with persistent innovation links employ nearly twice as many people with degrees than those with no innovation links. Therefore, companies with a higher percentage of employees with degrees are more likely to have persistent innovation links.

Innovation Capability

The analysis showed that in general, firms with a greater number of people working on R&D are more likely to have persistent and transitory innovation links. R&D expenditure rises quite substantially with the persistency of innovation links. On average firms with no innovation links spend £11.27 on R&D while firms with persistent innovation links spend £250.33 on average on R&D. Also R&D expenditure per employee rises with the more persistent innovation links. Veugelers (1997) found similar results in his study Belgian firms. He found that firms spending more on internal R&D have a significantly higher probability of cooperation in R&D. Similarly, Cassiman et al. (2002) provide evidence of a strongly positive effect of internal R&D activities on cooperation in R&D. Although, after the authors controlled for endogeneity, this effect became less significance.

As the persistency of innovation links increases a greater percentage of firms have an R&D dept. in their plant. 29% of firms with persistent innovation links have an R&D dept, while only 7% of firms with no innovation links have an R&D department. Similar results were found by Kleinknecht & van Reijnen (1992) indicating that if a firm has its own R&D department the probability of the firm collaborating with partners increases. The percentage of firms carrying out R&D carrying out R&D in the plant increases significantly with the persistency of links. On average 60% of

companies with persistent carry out R&D in their plant compared to only 31.8% of firms with transitory innovation links.

Innovation Activity

Addressing production innovation first, the results indicate that there is a significant positive association between the propensity of a firm's innovation linkages and product innovation. A higher percentage of firms with persistent or transitory innovation links are product innovators (72% and 83%, respectively) than firms with no innovation links (45%). Also firms with persistent innovation links have more new or improved products (11.78) than those with no innovation links (4.74).

Similar to production innovations, the results show a positive association between the propensity of a firm's innovation linkages and process innovation. A higher percentage of firms with persistent or transitory innovation links are process innovators 62% and 62%, respectively) compared with 33% of firms with no innovation links.

Government Assistance

A greater percentage of firms who received government assistance for product development in period 1 pursued innovation links. Therefore, if a firm has received government assistance for product development the more likely it is to have transitory or persistent innovation links. A greater percentage of firms who received government assistance for process development in period 1 pursued innovation links. A greater percentage of firms who received government assistance for exporting in period 1 pursued innovation links. 28.6% of companies with persistent innovation links and 44.8% of firms with transitory innovation links received government assistance for exporting. Therefore, if a firm has received government assistance for exporting the more likely it is to have transitory or persistent innovation links**.**

A significantly greater percentage of firms who received government assistance for non-specific R&D product development in period 1 pursued innovation links. 18.4% of companies with persistent innovation links and 13.8% of firms with transitory innovation links received government assistance for non-specific R&D. Therefore, if

a firm has received government assistance for non-specific R&D the more likely it is to have transitory or persistent innovation links.

Table 10
Innovation Links and Business Success

Changes between periods 2 and 4	Persistent Innovation Links	Transitory Innovation Links	No Innovation Links	Significance tests
Performance				
Change in Turnover	7400.15	840.37	6643.6	*t=0.124*
Change in Employment	5.59	5.30	3.04	*t=0.281*
Change in Export Sales	1.54	4.07	0.68	*t=0.175*
Human Resource Capability				
Change % of workforce with Degrees	2.73	1.11	0.76	*t=0.861*
Innovation Capability				
Change in R&D Expenditure	213.41	53.43	9.5	*t=1.459*
Change in R&D Exp. Per Employee	0.7	0.39	0.18	*t=1.433*
Innovation Activity				
Change in No. of New Products	14.74	120.24	26.4	*t=-0.501*
Change % of sales from new products	4.09	1.23	2.13	*t=0.345*

Significance levels: * p<0.10; **p<0.05; ***p<0.01

Innovation Links and Business Success

Performance

As regards turnover the results indicate that companies with no innovation links and persistent innovation links throughout the three periods had similar changes in average turnover 6643.60 and 7400.15, respectively) than companies with transitory innovation links (840.37). Companies with persistent or transitory innovation links had greater increases in employment levels between periods 1 and 3 2 (5.59 and 5.3 respectively). Companies with no innovation links had a change of 3.04 in employment between the two waves. Although, there is not a statistically significant difference between the two groups, no innovation links and persistent innovation links with regards to changes in employment levels between periods 1 and 3. Companies with persistent or transitory innovation links had larger increases in export sales between periods 1 and 3 (1.54% and 4.07% increases respectively) compared with companies with no innovation links (0.68% increase).

Human Resource Capability

Changes in the percentage of workforce with degrees increased with the persistency of links between periods 1 and 3. Companies with no innovation links had an increase of 0.76% of employees with degrees while companies with persistent innovation links had an increase of 2.73% of the workforce with degrees.

Innovation Capability

Companies with persistent or transitory innovation links had a much greater increase in R&D expenditure (213.41 and 53.43, respectively) than companies with no innovation links. Although, there is not a statistically significant difference between the two groups, no innovation links and persistent innovation links with regards to changes in R&D expenditure between periods 1 and 3. Changes in R&D expenditure per employee increased with the persistency of links between periods 1 and 3. Companies with persistent innovation links had an increase of 0.7 in R&D expenditure while companies with no innovation links had an increase of 0.18.

Innovation Activity

Companies with transitory links (120.24) throughout the three periods had on average more new products between periods 1 and 3 than companies with persistent or no innovation links. Therefore, there is not a statistically significant difference in the means of the groups. Companies with persistent innovations have nearly double the increase in the percentage of sales from new or modified or products between periods 1 and 3 compared to companies with no innovation links.

6. Summary and Conclusions

On the whole the empirical data indicates a number of relevant considerations. In the first instance the data suggests that there has been a move from closed to open innovation in Ireland with 43.2% of manufacturing plants in Ireland engaging in innovation links in 2000/02 compared with only 33.1% of plants in 1994/1996. When looking at the situation from a regional perspective it is obvious that firms in the

Republic of Ireland are engaging in a significantly greater amount of innovation linkages compared with Northern Ireland. Also, when looking at the use of horizontal and vertical linkages between the two regions, firms in ROI have consistently had a greater use of vertical and horizontal links across all three periods in comparison to NI plants. Although, when reviewing the three time periods the differential between the two regions in terms of the numbers of companies engaging in innovation links is closing. The intensity of vertical links is higher than horizontal links in both regions, again following previous results; ROI plants have a much greater intensity of links than NI firms.

When analysing innovation links based on firm size the results were consistent with previous studies (e.g. Fritsch and Lukas, 2001) with large firms pursing more innovation links than small firms. Foreign owned companies were more likely to have innovation links than indigenous companies, concurring with a previous study by Love and Roper (2001). As regards sectoral trends, companies in the food, drink and tobacco, chemicals, electrical and optical engineering and mechanical engineering sectors had a relatively high proportion of innovation links in all three periods. Overall, plants operating in sectors with higher technological requirements such as engineering and chemicals had a higher proportion of innovation links compared to companies operating in more traditional sectors such as paper and printing and textiles.

Cohen and Levinthal, (1989) assert that a firm's innovative capabilities depend on the ability of the firm to exploit external knowledge and on in house R&D efforts. Therefore, using cluster analysis this study also analysed the internal factors such as firm size turnover and employment; percentage of workforce with degrees; number for people working on R&D; R&D expenditure and government assistance are expected to affect the firms ability to exploit external knowledge. The results indicated that a firm's average turnover and employment levels are positively associated with more persistent innovation links. As regards performance indicators, companies with more persistent innovation links tended to have a higher sales growth compared to companies with no innovation links. The effect of employment growth on the persistency of innovation links was not statistically significant.

The empirical analysis reveals that exporting firms are more likely to have transitory or persistent innovation links, in line with a previous study by Link and Bauer (1987). Also the results indicated that companies with a higher percentage of employees with degrees are more likely to have persistent innovation links, illustrating the importance of human resource capability in the persistency of innovation links. As regards the innovation capability of firms, the analysis showed that in general R&D expenditure, number of people working on R&D, R&D expenditure per employee, percentage of R&D carried in plant and whether or not a firm had an R&D department in the plant were positively associated with more persistent innovation links. The results also show a positive association between the propensity of a firm's innovation linkages and product and process innovation. A higher percentage of firms with persistent or transitory innovation links are process innovators 62% and 62%, respectively) compared with 33% of firms with no innovation links.

The results also showed that if a firm had received government assistance for product or process development, for exporting non-specific R&D the more likely it is to have transitory or persistent innovation links. These results demonstrate the effect and importance of government assistance on R&D and innovation linkages, supporting the move from closed to more open innovation.

The analysis also looked at innovation links and business success, looking at performance, human resource, innovation capability and innovation activity characteristics. Firstly, performance indicators such as change in turnover and change in employment did not vary over the period when analysing the persistency of innovation links. Although, companies more persistent innovation links had larger increases in export sales between the periods. Changes in the percentage of workforce with degrees increased with the persistency of links between periods 1 and 3, although these results were not statistically significant. Companies with more persistent innovation links had a much greater increase in R&D expenditure and R&D expenditure per employee than companies with no innovation links. As regards innovation activity, companies with persistent innovations had nearly double the increase in the percentage of sales from new or modified or products between periods 1 and 3 compared to companies with no innovation links.

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