45th Congress of the European Regional Science Association
23-27th August 2005, Amsterdam

Measuring the Impact of Grant Support for Innovation: Panel Data Evidence for Irish Firms

Stephen Roper* and Nola Hewitt-Dundas**

* Aston Business School, Aston University, Birmingham, B4 7ET.
E-mail: s.roper@aston.ac.uk

** School of Management and Economics, Queen's University Belfast, Belfast, BT7 1NN
E-mail: nm.hewitt@qub.ac.uk

Preliminary Draft – 15th June 2005

Abstract

Public support for private R&D and innovation is part of most national and regional innovation support regimes. In this paper we evaluate the effectiveness of such support in boosting innovation success using panel data evidence for manufacturing plants in Ireland and Northern Ireland. Data is taken from the Irish Innovation Panel and covers the period 1994-2002. The empirical approach adopted follows recent studies in the evaluation literature on small business policy and corrects for the effects of selectivity bias. Our analysis suggests a number of results. First, development agencies in Ireland and Northern Ireland seem to have effectively targeted innovation support on firms which would otherwise have under-performed in terms of innovation. Secondly, innovation support has been effective in raising innovation levels among assisted firms, a very positive policy result. Third, both internal and external knowledge sources prove important for innovation success as does the quality of firms' resource base. Overall, our analysis suggests a 'positive' policy message emphasising the potential significance of public support for firms' innovation activity. It also suggests the potential importance of selection effects in such policy initiatives and the misleading nature of analyses which fail to take such effects into account.

Measuring the Impact of Grant Support for Innovation: Panel Data Evidence for Irish Firms

1. Introduction

Recent reviews of innovation policy regimes in different countries (e.g. EU, 2003), have emphasised the wide variety of approaches being used to support firms' innovation activity. EU (2003), for example, suggests that the innovation budget allocation in the UK mirrors relatively closely that in the US with support balanced roughly equally between fiscal incentives for innovation, subsidy measures and 'integrated packages of support'. Other countries adopt different approaches with Finland emphasising direct support measures (subsidies and loans) and France placing more emphasis on direct credit and loan support[1]. In each case, however, grant support for R&D and innovation remain almost ubiquitous, particularly as a means of stimulating innovative activity among smaller firms or those innovating for the first time. This reflects general arguments that small firms are likely to be more resource constrained than larger firms, so limiting their innovative activity (e.g. ref on resource constraints in small firms), and more specific assertions that market failures in terms of, say, the availability of finance for innovation may be pressing for smaller companies (e.g. Martin and Scott, 2000)[2].

This policy emphasis on public support for private sector R&D and innovation activity is largely justified by the existing empirical evidence which generally suggests a degree of additionality from public support for private R&D and innovation activity (e.g. Griliches, 1995; Mamuneas and Nadiri, 1996)[3]. This effect

---

[1] In the UK, for example, 29 per cent of the innovation budget comprises subsidy or grant schemes compared to 22 per cent in the Netherlands, 25 per cent in France, 47 per cent in Finland and 42 per cent in the US. New Zealand is a marked exception with almost no innovation grants and innovation support offered primarily through fiscal measures (EU, 2003, Table 5).

[2] For a more general discussion of the market failure justification for innovation policy see, for example, Metcalfe (1997).

[3] This clearly depends on the extent of additionality in publicly financed, private R&D, on which see Griliches (1995). Interestingly, for the US, Mamuneas and Nadiri (1996) identify some differences between sectors in this respect, finding a substitute relationship in low technology industries and a weak substitute relationship in high-tech sectors. Thus there is evidence of some crowding-out, particularly in the low-tech sectors.

can operate through a number of different organisational mechanisms, however. First, and most obviously, public support for private R&D may contribute to firms' knowledge stocks. Trajtenberg (2000), for example, in his examination of government support for commercial R&D in Israel, emphasises the positive link between public R&D support and firms' proprietary knowledge base. This increment to firms' stock of knowledge capital may then contribute to enhanced business performance (e.g. Klette and Johansen, 1998), as well as enhancing firms' ability to conduct future research projects (e.g. Mansfield and Switzer, 1984; Luukkonen, 2000)[4]. Second, publicly funded R&D activity may contribute to developments in firm's human resources and hence contribute to absorptive capacity (e.g. Roper and Love, 2005) and innovation activity (e.g. Michie and Sheehan, 2004; Freel, 2005). Sakakibara (1997) p. 462, for example, indicates that the managers of publicly supported collaborative R&D projects in Japan rated researcher training as the most important benefit which their companies derived from their project[5].

Third, public support which encourages firms to increase their level of R&D or innovation activity, this may also improve firms' ability to absorb R&D results or knowledge from elsewhere (e.g. Cohen and Levithal, 1989 and 1990). For example, Veugelers and Cassiman (1999) in their analysis of Belgian data suggest that firms undertaking in-house R&D benefited more from external information sources than companies which had no in-house R&D activity. Cassiman and Veugelers (2002) also emphasise the complementarity between internal and external R&D activity, and demonstrate that firms engaging in both activities introduce more innovative products than firms engaged in either external or internal R&D alone[6]. Fourth, other reputational or 'halo' effects may also stem from receipt of public R&D support.

[4] Luukkonen (2000) also indicates that participation in the collaborative EU Framework programmes by Finnish firms laid the basis for future R&D by contributing to firms' involvement and influence in standards negotiations, viz. participation 'provided background information for standardisation negotiations … [and] … facilitated their contacts, since the experts of the companies could get better acquainted with each other, which again helped their interactions. It was a question of an intangible impact' (p. 716)

[5] Somewhat surprisingly, this 'intangible' benefit from collaborative R&D was seen as more important than 'increase in the awareness of R&D in general', 'breakthrough in a critical technology', and 'accelerated development of the technology'.

[6] More specific evidence of the complementarity of publicly supported R&D and firms' other internally-funded R&D activity comes from Ballesteros and Rico (2001). They conduct an econometric analysis of the Spanish 'Concerted Projects' support scheme and demonstrate that Spanish firms which were more R&D intensive were also more likely to make use of government funding for collaborative university-business R&D projects.

Powell (1998), for example, points out, in the context of R&D collaboration in technology intensive industries, that 'a firm's portfolio of collaborations is both a resource and a signal to markets, as well as to other potential partners, of the quality of the firm's activities and product'. (p.231). Fifth, public funding of R&D may also create the potential for R&D cost savings through collaborative R&D and the sharing of research results. Irwin and Klenow (1996), for example, examined the Sematech collaborative R&D facility, set up by the US semiconductor industry in 1987 with substantial financial support from government. They compared the R&D intensity of Sematech member and non-member companies, and conclude that participation in the Sematech collaboration reduced members' R&D spending by 9 per cent.

A key issue in each of these studies' attempts to evaluate the impact of R&D or innovation support is the extent to which this is 'additional', i.e. represents R&D or innovation activity which the firm would not have undertaken without public assistance (e.g. English Partnerships, 2004). At programme level, additionality is often assessed by combining the impact on participating firms and the percentage of projects which were 'additional' (e.g. Lenihan et al, 2005). In one important respect, however, this type of approach may provide a misleading indication of the true impact of any policy intervention due a confusion of 'selection' and 'assistance' effects. In other words, if the firms selected for assistance were either above or below average performers without assistance this might impart a bias to any assessment of the true impact of assistance (see, for example, the discussion in Madalla, 1983). In this paper we apply an evaluation approach derived from the literature on the evaluation of small business development policy which allows us to decompose the total effect of public innovation support into 'selection' and 'assistance' components (see for example, Storey, 2000; Roper and Hewitt-Dundas, 2001; Roper and Hart, 2004). However, we also extend the existing approach to a panel data context, allowing us to control for temporal changes in the factors determining selectivity.

The remainder of the paper is organised as follows. Section 2 outlines the economic and policy setting for our analysis which focuses on the impact of innovation support in Ireland and Northern Ireland over the 1994 to 2002 period. This is important in the context of the current paper both because the key focus is on the effectiveness of policy but also because systemic approaches to innovation stress the importance of the historical, economic and institutional context within which innovation takes place (e.g. Cooke et al., 1997; Edquist, 2004).

2. Economic and Policy Context

Over the period considered here (1994-2002), Ireland and Northern Ireland experienced very different patterns of economic growth (Figure 1), suggesting marked changes in the market incentives for investments in R&D and innovation[7]. In Ireland – the Celtic Tiger – GDP grew by an average of 7.2 per cent per year from 1990 to 2000, while real GNP grew by 6.3 per cent per year, largely due to continued inward investment and re-investment in the high-tech sectors[8]. For Northern Ireland, the 1990s was marked by more steady output growth of 3.2 per cent per year in 1990-98, but this still compared favourably to growth rates in the UK (2.1 per cent pa) and EU (1.8 per cent pa) during the same period. (e.g. Morahan, 2002) [9]. Taken together, Ireland and Northern Ireland had an economic growth rate of about 5.4 per cent per year through the 1990s, the highest growth rate in the EU and the second highest in the OECD. From 2000-2002, the economic situation looked very different, however, with manufacturing output actually falling in Northern Ireland, while the rate of growth of output in Ireland slowed considerably (Figure 1).

The 1990s were also marked by significant changes in R&D and innovation policy in both Northern Ireland and Ireland, although in both areas a strongly interventionist innovation support regime was in operation. This intervention was generally justified in terms of broadly defined economic development objectives[10]. In Ireland, for example, the Culliton Report of 1992, noted that Ireland "was placed 22nd out of 23 industrial countries in its capacity for innovation, in the perception of international industrialists" (Culliton 1992 p. 55). Culliton argued that this justified active State involvement in the promotion of R&D, because: "Without state support and incentives the degree of investment in technology will be less than is desirable from the point of view of national economic development" (Culliton 1992 p. 55). More

---

[7] For a detailed comparison see O'Malley and Roper, 2004.
[8] GDP is conventionally used in making international comparisons. However, in the case of the Republic of Ireland GNP is generally regarded as more meaningful, since it excludes the substantial profits of foreign multinational companies that are withdrawn from the country.
[9] UK and EU data from *OECD Historical Statistics 1970-1999*.
[10] Although see Lenihan, Hart and Roper (2005) on the ambiguity of objectives of much Irish industrial policy and consequent difficulties in ex post evaluation.

specifically, the Culliton report advocated that support for innovation and R&D in Ireland should be focussed on developing capability in indigenous industry in Irish firms (e.g. Wrynn, 1997). Essentially similar concerns were evident in Northern Ireland, with both government reports (e.g. IRTU, 1992) and academic studies (e.g. Harris and Trainor, 1995) reflecting low levels of R&D and innovation in the region, and doubts about the strength and connectivity of the wider UK innovation system (e.g. Walker, 1993).

EU Objective 1 status – which benefited both Ireland and Northern Ireland throughout most of the period considered here - was also an important influence in the support regime for innovation in both areas. In Ireland, for example, the Operational Programme for Industrial Development, 1989-93 provided funding for capability development, while the subsequent 1994-99 Operational Programme had a specific sub-programme for research and development[11]. In Northern Ireland too, EU funding was an important component of R&D support, directly funding R&D infrastructure projects as well as providing co-funding for a number of regional innovation support programmes[12] . Developments in R&D and innovation support later in the 1990s continued the focus on developing innovation capability in indigenously-owned firms. In Ireland, the RTI scheme was launched in 1997, for example, with wide ranging objectives one of which was to introduce firms to R&D and innovation for the first time[13]. A similar emphasis has also characterised policy priorities in innovation support in Northern Ireland, with a focus on encouraging firms to engage in R&D and innovation for the first time. The Compete programme, for example, which provides support for near-market innovation 'has always attracted significant interest from companies engaging in R&D for the first time and 54 per cent of … applications to the programme were first time users' (Invest NI, 2003, p. 4).

---

[11] Cogan and McDevitt (2000: 11) describe EU involvement in R&D in Ireland as having been of 'critical importance' to Irish S&T policy. They describe three benefits of the EU involvement. Firstly, they cite the organisational and institutional learning it engendered. They state, rather philosophically, that Ireland missed out on the industrial revolution and somehow expected to catch up with other nations by using imported innovation and without building up a domestic innovation and R&D capability. Secondly, the EU structural funds brought with it a disciplined evaluation of policy, something which was missing from policy prior to this. Thirdly, rather than concentrating on research that had little bearing on Irish industry, the Structural Funds were geared towards stimulating a self-sustaining capacity for innovation.

[12] See, for example, Roper (1998) on Compete and Roper (2001) for a more detailed overview of the innovation support regime in Northern Ireland.

[13] Following some institutional changes in 1998, the RTI scheme was implemented through Enterprise Ireland, the agency specifically charged with developing the capacity of indigenous Irish firms.

Changes in innovation support regimes in Ireland and Northern Ireland, and their increasing focus on developing indigenous capacity, was also reflected in changes in the overall levels of government investment in R&D and innovation support. In Ireland, government support for R&D and innovation activity – reflected in grant payments to firms – grew steadily through the 1990s from €   m pa to around €   m pa (Figure 2), while that in Northern Ireland remained relatively stable at an annual overall level of …€…….m. Despite these levels of support business, and some increase during the period, R&D activity in both Ireland and Northern Ireland remained relatively low by international standards through to 2001.

The different elements of our contextual discussion have implications in terms of our assessment of the impact of innovation support measures. First, differences in the economic development and policy environment in Ireland and Northern Ireland suggest the potential importance of allowing for location in our modelling strategy (i.e. whether firms were located in Northern Ireland or Ireland). Second, over the period being considered, policy measures, instruments and administrative structures have changed significantly with, for example, the advent of Enterprise Ireland in 1998 in Ireland and the introduction of Compete in Northern Ireland in 1994. This suggests the potential importance of allowing for temporal changes in the factors which might be shaping the likelihood that firms' received innovation support. This is supported by very different trends in Ireland and Northern Ireland in terms of the overall level of public support for business R&D and innovation (Figure 2). Third, the policy priority given to targeting firms engaging in R&D or innovation for the first time, in both Ireland and Northern Ireland, is likely to mean that the assisted firms were below average in size and, also perhaps, concentrated in sectors with medium to low R&D intensity[14]. If this is the case, and means that without assistance the group of assisted firms would have had a below average level of innovative activity, there is likely to be a negative selectivity effect with the potential for a negative bias in terms of the policy impact suggested by any more simple treatment model (e.g. Madalla, 1983).

[14] Roper et al (2004), Table 2.2, p. 19, for example, suggests that 40.8 per cent of plants in Ireland with 10-19 employees had introduced a new or improved product from 2000-02 compared to 79.9 per cent of plants with 100 or more employees. Similarly, 49.5 per cent of plants in Northern Ireland had introduced a new or improved product over the same period compared to 68.2 per cent of larger firms.

This suggests the potential value of explicitly allowing for selectivity bias in our modelling approach.

3. Modelling Approach

Our modelling approach is based around the now familiar notion of an innovation or knowledge production function (e.g. Geroski, 1990; Harris and Trainor, 1995; Love and Roper, 2001). This relates knowledge inputs to innovation outputs, with the argument here being that government support may - in some way – augment innovation outputs given any level of innovation inputs. If I is an indicator of innovation outputs – here the proportion of sales derived from new or innovative products - the innovation production function can be stated as:

$$I = \beta' x + \delta z + \varepsilon \quad (1)$$

Where x is a vector of firm and market characteristics reflecting firms' knowledge gathering and combination activities, and z is a binary treatment variable taking value 1 if a firm received government support for innovation and 0 otherwise. In this model the size, sign and significance of the coefficient on the treatment term (i.e. δ) will give an indication of the impact on business performance of receiving grant support. Other studies have shown, however, that such coefficients give an unbiased indication of the effect of grant support only if support is randomly distributed across the population of firms. Where there is any element of selection in the award of grants – due either to self selection in grant application or selectivity in awarding support - the coefficients on the treatment terms will reflect the combination of 'assistance' and 'selection' effects. This can work in a number of ways. For example, a development agency may wish to target its assistance at firms which had performed well in the past, i.e. it may wish to 'back winners'. In this case, if the selection effect was positive (i.e. the agency succeeded, say, in targeting highly innovative firms), direct estimation of the treatment coefficients would over-estimate the true assistance effect (Greene, 1997, p. 982). Conversely, if a development agency succeeded in targeting firms with below average innovation performance, direct estimation of the treatment effect would induce a negative bias in the policy effect.

Rather than direct estimation of equation (1) a preferable approach is therefore to allow explicitly for this type of selection bias (see Maddala, 1993, pp. 257-290 for a general discussion). Specifically, we assume that the likelihood or probability of receiving assistance (z^*) is itself related to a set of business characteristics, v. This suggests a complete model of the form (Greene, 1995, p. 642):

$$I = \beta' x \quad + \quad \delta z \quad + \varepsilon$$

$$z^* = \gamma' v + w \qquad (2)$$

$$w, \varepsilon \sim N(0,0,\sigma_{\varepsilon}^2,\sigma_w^2,\rho)$$

What we observe ex post, of course, is not the probability of receiving assistance (z^*) but a binary variable (z) that indicates whether a firm did or did not receive support for innovation or R&D. That is:

$$z = 1 \text{ if } z^* > 0 \qquad (3)$$

$$z = 0 \text{ if } z^* <= 0$$

The appropriate estimation method for this type of model is the two-stage procedure outlined in Heckman (1979). This involves the estimation of a Probit model to estimate γ and the incorporation of a selection parameter – the inverse Mills ratio - in the treatment model for business performance (see Greene, 1995, p. 639 for details).

Two main issues arise in applying this model to the specifics of our data. First, our contextual discussion suggested that the probability of receiving assistance for any given type of firm may have varied both through time and between Northern Ireland and Ireland – in other words the parameter vector γ may differ between areas and time periods. To capture this possibility, we estimate separate cross-sectional probit models for the probability of receiving assistance in each area and period covered by the data and then pool the resulting selection parameters – the IMRs – in the panel estimation of the innovation production function. Second, an ideal specification for the Heckman model involves variables in the probit model which help to predict the probability of receiving assistance but which have no influence in the innovation production function. In contexts where fieldwork is undertaken specifically to enable this type of analysis it is possible to meet this restriction in full (e.g. Roper and Hart, 2004). In our context here, and others where secondary data analysis is involved, this restriction is more difficult to achieve. The best that can be done in this context is to avoid as much overlap as possible between the vectors x and v, something which is helped in our case by the different estimation periods covered by the probit estimation and that used in the innovation production function (see Harris and Robinson, 2004, pp 536-7 for a discussion).

4. Data

Our empirical analysis is based on data from the Irish Innovation Panel (IIP) which provides information on knowledge use, government support and the innovation performance of manufacturing plants throughout the Ireland and Northern Ireland over the period 1991-2002. The IIP comprises four linked surveys conducted using similar survey methodologies and questionnaires with common questions. Each survey covers the innovation activities of manufacturing plants with 10 or more employees over a three year period (Roper et al, 1996; Roper and Hewitt-Dundas, 1998; Roper and Anderson, 2000; Roper et al., 2004). Each wave of the IIP was undertaken by post using a sampling frame provided by the economic development agencies in Northern Ireland and Ireland. The initial survey, undertaken between October 1994 and February 1995, related to plants' innovation activity over the 1991-93 period, and achieved a response rate of 38.2 per cent (Roper et al., 1996; Roper and Hewitt-Dundas, 1998, Table A1.3). The second survey was conducted between November 1996 and March 1997, covered plants' innovation activity during the 1994-96 period, and had a response rate of 32.9 per cent (Roper and Hewitt-Dundas, 1998). The third survey covering the 1997-99, period was undertaken between October 1999 and January 2000 and achieved an overall response rate of 32.8 per cent (Roper and Anderson, 2000). The fourth survey was undertaken between November 2002 and May 2003 and achieved an overall response rate of 34.1 per cent (Roper et al., 2004).

In the current analysis to allow greater variable choice, we use only the second, third and fourth survey results. The two variables of interest are, in the probit, the probability that a firm received government support for product development in the previous three years, and in the innovation production function, the proportion of firms' sales derived from products newly introduced in the previous three years. This might be considered an indicator of innovation success, reflecting both the market introduction and sales of innovative products. Over the whole sample period 23.1 per cent of firms in Northern Ireland received support for product development compared to 25.6 per cent in Ireland (Annex 1). Similarly, the proportion of innovative products in sales (innovation success) averaged 13.3 per cent in Northern Ireland and 16.5 per cent in Ireland (Annex 1).

In the probit model for the probability of receiving innovation grant support we include three main groups of variables. The first - designed to reflect the size and sector of the firm is intended to reflect any targeting of assistance by development agencies on firms in any particular firm sizeband or sectoral group. Second, we include a variable designed to reflect other grant support received by firms – relating to process change. Our argument here is that firms receiving this type of assistance might be more aware of potential assistance for product development and this might increase the probability of receiving product development support. Finally, we include a group of variables designed to reflect the innovative capabilities of the enterprise, a potentially important factor in development agencies' choice of firms to assist.

The innovation production function requires measures of knowledge sourcing activity, and of plants' market position and resource base. Measuring the intensity of firms' knowledge sourcing through R&D is relatively straightforward with standard indicators (used by Crépon et al., (1998), Lööf and Heshmati (2001, 2002), and Love and Roper (2001a)) measuring R&D employment relative to total employment. Measuring the intensity of knowledge sourcing through firms' supply-chain and non supply-chain innovation linkages is more experimental, and here we follow Love and Roper (1999, 2001a) who develop intensity scores for the extent of firms' external contacts. More specifically, we construct intensity scores for each plant's knowledge sourcing through supply-chain and non supply-chain collaboration based on the number of types of organisation with which the firm is undertaking collaborative innovation activity. For example, we identify five types of potential supply-chain partners (customers, suppliers, competitors, other group companies and joint ventures): plants undertaking innovation collaboration with three of these types of partner 'score' 60 per cent, plants collaborating with all five types of partner score 100 per cent and so on. Reflecting both those plants with no supply chain links and those with links, the average value of the supply chain collaboration variable for the whole sample was 18.33 (Table 1). Non supply-chain linkages are constructed in a similar way, using links with four types of possible partners (consultancies, universities, government bodies and industry research establishments).

Market position indicators include a size variable (employment) and its square, reflecting the frequent finding of a quadratic relationship between size and innovation, and dummy variable indicators of the plants' form of production activity. The strength of each plant's internal resource base is proxied by a variety of measures, including whether or not the plant is part of a multi-plant group, whether it is externally owned and whether there is any R&D relevant to the plant carried out elsewhere within the group. These measures of intra-group resources have proved important in previous research on innovation (Love *et al.,* 1996; Love and Roper, 1999, 2001). Indicators of labour and capital inputs are also included (percentage of workforce with a degree and percentage with no qualifications; capital investment relative to turnover). Finally, to reflect the potential impact of assistance we include the treatment effect – a dummy variable indicating whether the firm had received any government assistance for product development during the survey period. To reflect any selection effect we also include the IMR derived from the probit model.

5. Empirical Results

Our results divide naturally into those related to the probability of receiving assistance for product development – the probit models – and those related to the impact of this assistance on product change – from the Tobit models for innovation success. Probit models for the probability of receiving product development support are given in Tables 1 and 2 for each area and period separately. Table 4 reports Tobit models for innovation success in the combined sample for each period and area.

In terms of the probability of receiving assistance for product development we find little consistent evidence in either Northern Ireland or Ireland of any targeting by sector or plant Sizeband (Tables 1 and 2). It is clear, however, from the sizes and signs of the coefficients that smaller firms were more likely to receive support for product development support than larger firms. In addition our evidence suggests only a weak link between firms' process innovation activity and the probability of receiving grant support for product development. Some linkages were also evident with firms' characteristics, with external ownership reducing the probability of receiving grant support but R&D and linkages generally having a positive effect on the probability of receiving product development assistance. The strongest factor, however, was whether or not the firm received grants for process development suggesting the potential importance either of related information channels or the potential for firms to receive packages of support covering both product and process development.

The results of the fixed-effects Tobit model for innovation success are shown in Table 4. The two key variables of interest here are the coefficients on the treatment term reflecting government support for product development and the assistance term (the IMR) reflecting any selection bias. In the three models reported in Table 4 these effects are reassuringly consistent: government support for product development has a positive and strongly significant effect on innovation success, and there is a consistent negative selection effect. In other words, as our earlier contextual discussion suggested assistance was being targeted as firms which would otherwise have under-performed in terms of innovation success. Without the selection criteria the implication is of a negative bias in the government assistance effect – i.e. the positive effect on innovation of government intervention would have been underestimated by around a half.

Other factors also prove important in determining innovation success. For example, all three knowledge sourcing activities have a positive effect on innovation success, with a clear hierarchy of effects running from R&D intensity through supply chain collaboration to non-supply chain collaboration. This reflects the findings of other studies which have emphasised the importance of boundary-spanning networks for innovation (Oerlemans et al., 1998; Love and Roper, 2001). At first sight, the positive sign on all three coefficients appears to suggest that there is a complementary rather than substitute relationship between the three knowledge-sourcing activities. However, the introduction of cross-product variables somewhat qualifies this. The positive impact of both supply chain and non-supply chain linkages on innovation is reduced in the presence of R&D, although the size of the effect is small, and having both forms of collaborative activity in tandem also slightly reduces the positive impact of each separately. Overall, therefore, the results of the knowledge sourcing variables suggest that it pays to access both internal and external knowledge sources for innovation, but at the margin there is some degree of substitutability between them.

The market position indicators suggest that employment has a U-shaped relationship with innovation success, but virtually all plants in the sample lie on the downward-sloping part of the curve[15]. Relative to plants undertaking continuous production, those mainly producing large batches are relatively successful innovators, while those with one-off production methods are relatively less 'successful'. There is also no evidence of any 'learning' effect with respect to plant vintage, something which might have been expected if innovation was the type of cumulative causation process envisaged in the Schumpeter Mark II model. This latter finding reflects the results of other recent studies which have emphasised the lack of persistence of innovation across different populations of companies and pointed instead to a polarised distribution of non-innovative and strongly innovative companies (e.g. Malerba et al., 1997; Cefis and Orsenigo, 2001).

A range of indicators of plants' resource base also prove important in determining the efficiency with which plants translate knowledge inputs into innovation success. Being part of a multi-plant operation has a substantial positive effect, which may, of course, be yet another facet of knowledge sourcing activity, especially where knowledge is tacit and there may be reasons to fear dissipation of property rights. However, the fact that there is no effect arising from having access to group R&D weakens the knowledge-sourcing argument, and indicates that the advantages of group membership may reflect the financial support which groups can provide, or some other advantage which is not directly R&D/innovation based. Perhaps surprisingly, the proportion of graduates in the workforce has no effect on innovation success. This does not indicate, however, that the qualifications issue is unimportant; the significantly negative coefficient on the proportion of the workforce with no qualifications suggests that mid-level qualifications may be an important determinant of innovation success, a factor emphasised previously in Ireland-Germany skill

[15] The turning point is around 2700 employees.

comparisons (e.g. Roper and Hoffman, 1993). Unsurprisingly, capital investment also has a strong positive effect on innovation success.

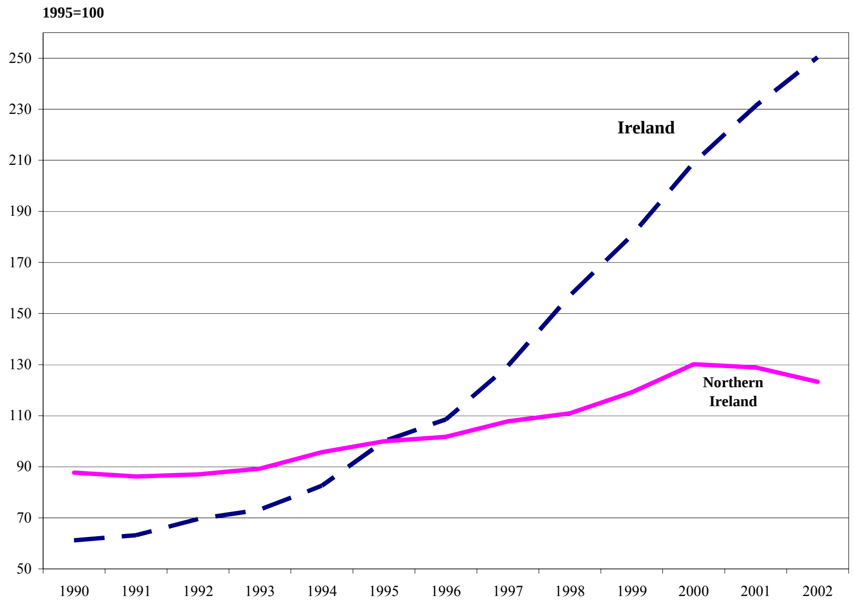
6. Conclusions

Our analysis based on data for Irish manufacturing firms confirms the potential positive contribution of public assistance for firms' innovation success. Moreover, we also demonstrate that without allowing for potential selection bias in the firms assisted this type of effect may be substantially under-estimated. In Ireland and Northern Ireland, public assistance for product development has been effectively targeted at smaller firms and new innovators, and seems to have had a significant positive effect on innovation success. This is clearly a welcome policy message given the ubiquity of such grant supports for innovation activity.

Our results also provide further support for the importance of external knowledge sources for innovation. A clear hierarchy does emerge, however, with in-house R&D dominating supply-chain collaboration which, in turn, dominates non-supply chain collaboration. In addition, however, we find evidence of substitutability between these knowledge sourcing activities in contrast to other studies which largely suggest a pattern of complementarity. In addition to these knowledge sourcing variables, we find strong evidence that innovation success (measured by the percentage of sales derived from new products), depends on plants' organisational context, skills, and capital investment.

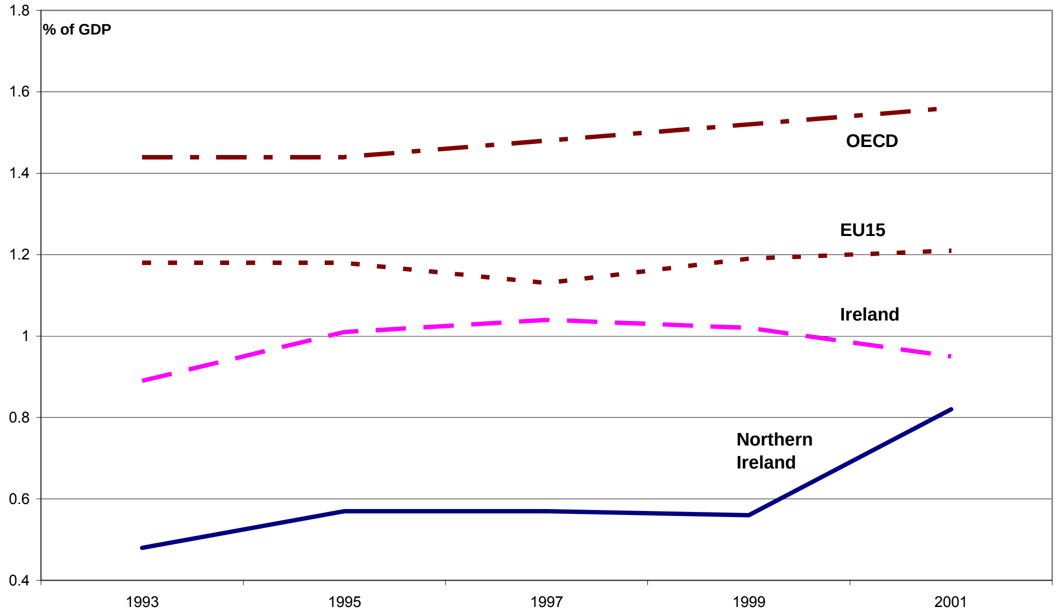
A number of policy conclusions follow from our analysis. First, it is clear that public support for product development can be effectively targeted and can be effective in boosting firms' innovation success. Investment in such support measures may therefore be seen as worthwhile either in isolation or as part of a package of innovation support measures. Second, our analysis emphasises the importance of boundary spanning links for innovation success. Policy measure to support collaboration are therefore likely to have positive innovation benefits as are those designed to strengthen firms internal R&D capability. Third, skill levels emerge as important in shaping firms innovation success. Measures to promote skill development are therefore likely to be doubly effective in increasing wealth creation both by promoting innovation and by increasing the effectiveness with which innovation activity is commercially exploited (e.g. Roper and Love, 2005). Fourth, significant sectoral differences are observed between innovation success and the effectiveness with which innovation success is translated into business performance. This suggests the potential importance of a sectoral dimension both of policies designed to support both innovation activity and exploitation.

Figure 1: Manufacturing Output Growth in Ireland and Northern Ireland: 1991-2002 (1995=100)



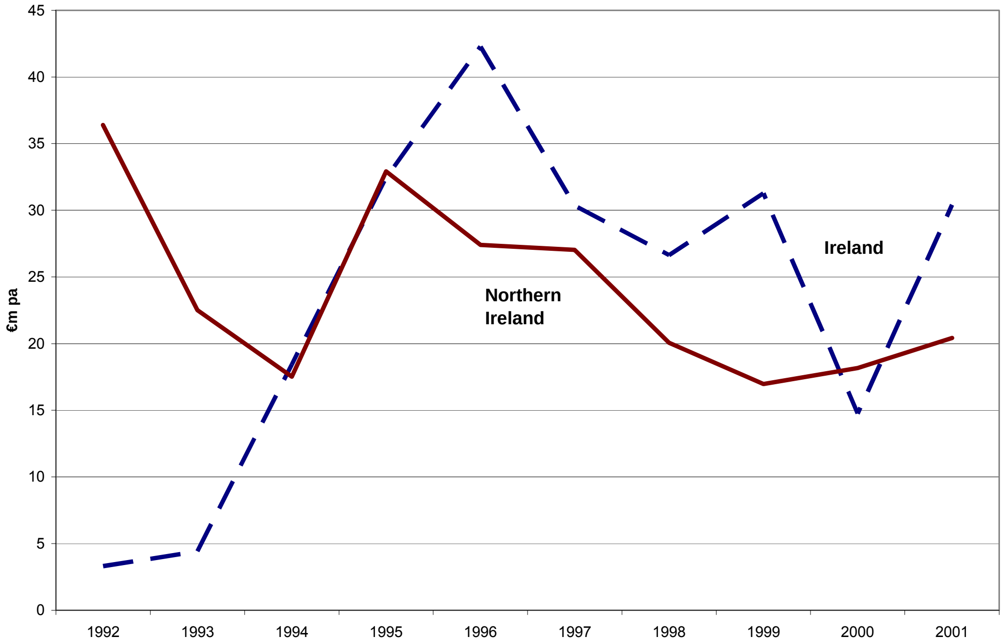
Sources: Northern Ireland, Department of Enterprise, Trade and Investment, Belfast; Ireland, CSO, Dublin.

Figure 2: Business R&D Expenditure as % of GDP (BERD)



Notes and Sources:

Figure 3: R&D and Innovation Grant Support in Ireland and Northern Ireland (€m pa)



Notes and Sources: Northern Ireland, nominal sterling data from IRTU Annual Reports. See Roper (2001) for details; currency conversion to € using data from http://www.x-rates.com. Ireland, nominal grants data provided by Forfas.

Table 1: Probit Models for the Probability of Receiving Innovation Grant Support: Northern Ireland

	1993-95			1996-99			2000-2002		
	Coeff	Std Err.	Signif.	Coeff	Std Err.	Signif.	Coeff	Std Err.	Signif.
Constant	-2.646	0.437	0.000	-2.166	0.303	0.000	-1.619	0.225	0.000
Employment 50-99	0.542	0.343	0.114	0.461	0.267	0.085	0.412	0.228	0.071
Employment 100-249	0.324	0.370	0.381	0.397	0.288	0.168	-0.237	0.319	0.458
Employment 250+	0.401	0.479	0.402	0.643	0.396	0.105	-0.425	0.456	0.352
Process Innovator	0.172	0.272	0.527	0.387	0.235	0.100	0.010	0.202	0.962
Externally Owned	-0.527	0.333	0.113	-0.176	0.243	0.469	-0.701	0.284	0.014
Govt. Ass. For Process Dev.	1.448	0.325	0.000	1.358	0.255	0.000	1.178	0.255	0.000
Non supply Chain Inn Links	0.002	0.005	0.653	0.008	0.006	0.182	0.010	0.005	0.035
Supply Chain Innovation Links	-0.004	0.006	0.478	-0.011	0.005	0.034	-0.004	0.005	0.436
Food, Drink And Tobacco	0.126	0.420	0.765	0.071	0.303	0.814	-0.321	0.267	0.228
Textiles And Clothing	-0.061	0.425	0.886	0.165	0.312	0.596	-0.703	0.382	0.066
Wood And Wood Products	0.292	0.544	0.591	-0.699	0.648	0.281	0.187	0.403	0.643
Paper And Printing	-0.171	0.627	0.785	-0.072	0.508	0.888	-0.690	0.464	0.137
Chemicals	0.235	0.610	0.700	-0.063	0.648	0.922	-0.015	0.435	0.972
Metals And Metal Fabrication	0.514	0.506	0.310	0.681	0.342	0.046	-0.661	0.413	0.110
Mechanical Engineering	0.361	0.427	0.399	1.687	0.451	0.000	0.162	0.362	0.654
Electrical And Optical Equipment	1.109	0.483	0.022	0.462	0.415	0.266	0.231	0.389	0.553
Workforce With Degree (%)	3.176	1.706	0.063	0.705	1.153	0.541	1.208	0.717	0.092
R&D In Plant	1.571	0.320	0.000	0.775	0.232	0.001	0.945	0.217	0.000
R&D Dept. In Plant	0.270	0.307	0.379	0.570	0.265	0.032	0.912	0.281	0.001
N		238			319			377	
Log Likelihood		-75.285			-109.41			-122.04	
$X^2()$		104.32 (ρ<0.000)			138.29 (ρ<0.000)			155.89 (ρ<0.000)	
Estrella		0.430			0.422			0.407	
Veall/Zim.		0.589			0.572			0.568	

Table 3: Probit Models for the Probability of Receiving Innovation Grant Support: Ireland

	1993-95			1996-99			2000-2002		
	Coeff	Std Err.	Signif.	Coeff	Std Err.	Signif.	Coeff	Std Err.	Signif.
Constant	-1.757	0.318	0.000	-1.745	0.242	0.000	-1.725	0.256	0.000
Employment 50-99	0.116	0.233	0.617	0.075	0.206	0.715	-0.818	0.262	0.002
Employment 100-249	0.377	0.241	0.117	0.182	0.207	0.381	-0.245	0.283	0.386
Employment 250+	-0.053	0.318	0.867	-0.271	0.285	0.342	-0.515	0.350	0.140
Process Innovator	0.131	0.217	0.547	-0.034	0.176	0.847	-0.381	0.214	0.074
Externally Owned	-0.353	0.212	0.096	-0.342	0.184	0.063	-0.198	0.257	0.440
Govt. Ass. For Process Dev.	1.113	0.208	0.000	1.413	0.190	0.000	1.475	0.251	0.000
Non supply Chain Inn. Links	0.005	0.004	0.185	0.008	0.003	0.023	0.000	0.005	0.941
Supply Chain Innovation Links	0.001	0.004	0.890	-0.007	0.004	0.042	0.007	0.004	0.112
Food, Drink And Tobacco	0.131	0.284	0.645	0.384	0.242	0.113	-0.160	0.286	0.575
Textiles And Clothing	-0.249	0.366	0.495	0.270	0.290	0.351	-0.319	0.424	0.452
Wood And Wood Products	-0.405	0.456	0.374	0.306	0.407	0.452	0.204	0.480	0.671
Paper And Printing	-0.199	0.452	0.659	-0.404	0.467	0.387	-0.487	0.635	0.443
Chemicals	-0.156	0.389	0.688	0.047	0.319	0.882	0.057	0.374	0.879
Metals And Metal Fabrication	0.275	0.373	0.461	0.002	0.278	0.993	-0.381	0.353	0.280
Mechanical Engineering	-0.062	0.415	0.881	0.794	0.279	0.005	0.356	0.334	0.286
Electrical And Optical Equip	0.268	0.316	0.395	0.494	0.260	0.058	0.382	0.297	0.198
Workforce With Degree (%)	-1.284	1.133	0.257	0.827	0.740	0.264	0.091	0.610	0.882
R&D In Plant	0.499	0.224	0.026	0.936	0.178	0.000	1.291	0.239	0.000
R&D Dept. In Plant	1.163	0.226	0.000	0.527	0.182	0.004	0.534	0.234	0.023
N		396			492			397	
Log Likelihood		-138.06			-196.62			-130.34	
$X^2()$		164.8 (ρ<0.000)			211.83 (ρ<0.000)			156.82 (ρ<0.000)	
Estrella		0.406			0.411			0.390	
Veall/Zim.		0.557			0.545			0.554	

Table 4: Tobit Models for Innovation Success: Combined Sample Ireland and Northern Ireland

	Model 1			Model 2			Model 3		
	Coeff	Std Err.	Signif.	Coeff	Std Err.	Signif.	Coeff	Std Err.	Signif.
R&D Intensity	1.726	0.200	0.000	1.881	0.203	0.000	1.867	0.199	0.000
Supply Chain Innovation Links	0.379	0.043	0.000	0.379	0.042	0.000	0.376	0.042	0.000
Non supply Chain Inn Links	0.162	0.061	0.008	0.189	0.061	0.002	0.188	0.061	0.002
Nsc Links With R&D	-0.021	0.005	0.000	-0.022	0.006	0.000	-0.022	0.006	0.000
Sc Links With R&D	-0.014	0.006	0.018	-0.015	0.006	0.011	-0.015	0.006	0.012
Sc And Nsc Links	-0.004	0.001	0.000	-0.004	0.001	0.000	-0.004	0.001	0.000
Employment 50-99	0.968	1.973	0.624	2.684	1.999	0.179	2.655	1.997	0.184
Employment 100-249	-4.291	2.169	0.048	-3.255	2.168	0.133	-3.239	2.162	0.134
Employment 250+	1.217	2.659	0.647	3.549	2.689	0.187	3.534	2.684	0.188
Plant Vintage (Yrs)	0.021	0.028	0.438						
Production Mainly One-Offs	-5.629	1.949	0.004	-4.578	1.973	0.020	-4.610	1.969	0.019
Production Small Batches	-0.999	1.460	0.494	0.213	1.467	0.885			
Production Large Batches	7.100	1.545	0.000	6.158	1.517	0.000	6.076	1.480	0.000
Part Of Multi-Plant Operation	4.387	2.142	0.041	7.075	2.104	0.001	6.993	2.089	0.001
Externally Owned	-5.751	2.200	0.009	-7.359	2.198	0.001	-7.358	2.199	0.001
Workforce with degree (%)	0.020	0.069	0.776	-0.024	0.071	0.739	-0.093	0.024	0.000
Workforce With No Qualifications (%)	-0.108	0.024	0.000	-0.095	0.024	0.000			
Govt. Ass For Product Dev	13.775	2.694	0.000	12.877	2.648	0.000	12.862	2.636	0.000
Capital Inv Per Employee	0.085	0.035	0.014	0.091	0.036	0.011	0.090	0.035	0.011
Food, Drink And Tobacco	-0.535	2.365	0.821	-1.914	2.340	0.413	-2.018	2.319	0.384
Textiles And Clothing	10.682	2.901	0.000	10.808	2.852	0.000	10.760	2.848	0.000
Wood And Wood Products	-3.194	3.650	0.382	-3.110	3.676	0.398	-3.219	3.662	0.379
Paper And Printing	-9.312	3.857	0.016	-7.118	3.697	0.054	-7.199	3.690	0.051
Chemicals	0.738	3.358	0.826	0.911	3.450	0.792	0.725	3.406	0.832
Metals And Metal Fabrication	2.588	2.609	0.321	0.161	2.658	0.952	0.156	2.657	0.953

Mechanical Engineering	9.660	2.942	0.001	8.244	2.851	0.004	8.210	2.848	0.004
Electrical And Optical Equipment	5.258	2.576	0.041	1.971	2.575	0.444	1.850	2.539	0.466
Transport Equipment	-6.691	3.948	0.090	-8.610	4.050	0.034	-8.598	4.051	0.034
Selection Parameter	-6.874	1.831	0.000	-5.719	1.797	0.002	-5.712	1.788	0.001
N		2726			2726			2726	
		-			-			-	
Log Likelihood		3535.61			3705.48			3505.33	

Annex 1: Data Descriptives

	Northern Ireland		Ireland		Combined Sample	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Employment < 50	0.584	0.493	0.499	0.500	0.534	0.499
Employment 50-99	0.177	0.382	0.207	0.405	0.194	0.396
Employment 100-249	0.158	0.364	0.181	0.385	0.171	0.377
Employment 250+	0.081	0.273	0.114	0.318	0.100	0.300
Food, Drink And Tobacco	0.171	0.377	0.173	0.379	0.172	0.378
Textiles And Clothing	0.148	0.355	0.081	0.274	0.109	0.312
Wood And Wood Products	0.068	0.252	0.042	0.200	0.053	0.224
Paper And Printing	0.070	0.255	0.070	0.254	0.070	0.255
Chemicals	0.037	0.189	0.087	0.281	0.066	0.248
Metals And Metal Fabrication	0.085	0.279	0.110	0.312	0.099	0.299
Mechanical Engineering	0.090	0.286	0.067	0.250	0.077	0.266
Electrical And Optical Equipment	0.063	0.243	0.167	0.373	0.123	0.329
Transport Equipment	0.037	0.188	0.034	0.181	0.035	0.184
Process Innovator	0.536	0.499	0.632	0.482	0.592	0.492
Innovative Sales (%)	13.308	21.544	16.511	23.695	15.131	22.844
R&D In Plant	0.439	0.496	0.524	0.500	0.489	0.500
R&D Dept. In Plant	0.165	0.371	0.233	0.423	0.204	0.403
R&D Intensity	2.349	5.368	2.958	10.692	2.709	8.912
Supply Chain Innovation Links	16.475	25.348	19.699	26.114	18.330	25.836
Nsupply Chain Innovation Links	10.828	23.126	13.922	25.586	12.608	24.615
Nsc Links With R&D	46.572	325.030	70.858	355.720	60.871	343.552
Sc Links With R&D	44.151	163.917	93.513	516.713	73.215	410.825
Sc And Nsc Links	552.259	1482.438	694.444	1605.033	634.073	1555.465
Production Mainly One-Offs	0.180	0.384	0.164	0.370	0.170	0.376
Production Mainly Large Batches	0.283	0.451	0.302	0.459	0.294	0.456
Workforce With Degree (%)	0.076	0.105	0.097	0.123	0.088	0.116
Workforce With No Qualifications (%)	49.766	32.597	48.351	31.844	48.938	32.161

Part Of Multi-Plant Operation	0.373	0.484	0.534	0.499	0.466	0.499
Externally Owned	0.277	0.448	0.390	0.488	0.343	0.475
Capital Investment Per Employee	4.662	12.261	6.769	18.663	5.886	16.319
Govt. Assistance For Product Development	0.231	0.422	0.256	0.436	0.245	0.430
Govt. Assistance For Process Development	0.143	0.351	0.165	0.371	0.156	0.363
Govt. Assistance For Product Development	0.231	0.422	0.256	0.436	0.245	0.430

References

Cefis, E and Orsenigo, L (2001) 'The Persistence of Innovative Activities; A Cross Country and Cross-Sectors Comparative Analysis', *Research Policy*, 30, 1139-1158.

Conway S (1995) 'Informal boundary-spanning communications in the innovation process: an empirical study', *Technology Analysis & Strategic Management*, **7**, 327-42.

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

Morahan, T., 2002. "Progress in the NI economy – A UK regional comparison". DEL *Labour Market Bulletin*, No. 16, pp 39-46.

EU (2003) 'Raising EU R&D Intensity', Brussels.

Freel MS (2005) 'Patterns of innovation and skills in small firms', Technovation, 25, 2, 123-134

Geroski, P A (1990) 'Innovation, technological opportunity, and market structure', *Oxford Economic Papers*, 42, 586-602.

Greene, W H (1997) '*Econometric Analysis'*, Macmillan, New York.

Harris R I D and Trainor M (1995) 'Innovations and R&D in Northern Ireland manufacturing: a Schumpeterian approach', *Regional Studies*, 29, 593-604.

Invest NI (2003) Industrial Research and Technology Unit, Annual Accounts 2001 – 2002, Invest NI, Belfast.

Lööf, H and Heshmati, A (2001) 'On the Relationship Between Innovation and Performance: A Sensitivity Analysis', SSE/EFI Working Paper No 446, Stockholm School of Economics

Lööf, H and Heshmati, A (2002) 'Knowledge Capital and Performance Heterogeneity: A Firm Level Innovation Study', *International Journal of Production Economics*, 76, 61-85.

Love J H, Ashcroft B and Dunlop S (1996) "Corporate structure, ownership and the likelihood of innovation" *Applied Economics*, Vol 28, 737-46.

Love, J H and Roper, S (2001b) 'Outsourcing in the Innovation Process: Locational and Strategic Determinants', *Papers in Regional Science*, 80, 3, 317-336.

Love, J. H. and Roper, S. (1999) 'The determinants of innovation: R&D, technology transfer and networking effects', *Review of Industrial Organization*, vol. 15, 43-64.

Love, J. H. and Roper, S. (2001a) 'Location and network effects on innovation success: evidence for UK, German and Irish manufacturing plants', *Research Policy*, 30, 643-61.

Maddala, G (1993) '*Limited Dependent and Qualitative Variables in Econometrics'*, Cambridge University Press, New York.

Malerba, F Orsenigo, L and Peretto, P (1997) 'Persistence of Innovative Activities, sectoral patterns of innovation and international technological specialisation', *International Journal of Industrial Organisation*, 15, 801-826.

Martin, S Scott, J T (2000) 'The nature of innovation market failure and the design of public support for private innovation', Research Policy, 29, 4-5, 437-447.

Metcalfe, S (1997) 'Technology Systems and Technology Policy in an Evolutionary Framework', in '*Technology, Globalisation and Economic Performance'*, Archibugi, D and Michie, J (eds.), Cambridge University Press.

Nelson, R R and Winter, S G (1982) '*An Evolutionary Theory of Economic Change'*, Harvard University Press, Cambridge, Mass.

Oerlemans, L A G Meus, M T H and Boekema, F W M (1998) 'Do Networks Matter for Innovation? The Usefulness of the Economic Network Approach in Analysing Innovation', *Tijdschrift voor Economische en Sociale Geografie*, 89, 3, 298-309.

Roper S, Love J H, Ashcroft B and Dunlop S (2000) "Industry and location effects on UK plants' innovation propensity", *Annals of Regional Science*, 34, 489-502.

Roper, S and Anderson, J (2000) 'Innovation and E-Commerce – A Cross-Border Comparison of Irish Manufacturing Plants', NIERC Research Report 17.

Roper, S and Hewitt-Dundas, N (1998) 'Innovation, Networks and the Diffusion of Manufacturing Best Practice', NIERC Research Report 14, April, NIERC, Belfast.

Roper, S and Hewitt-Dundas, N (2001) 'Grant Assistance and Small Firm Development in Northern Ireland and the Republic of Ireland', *Scottish Journal of Political Economy,* 48, 1, 99-117

Roper, S and Hofmann, H (1993) 'Training and Competitiveness - A Matched Plant Comparison of Companies in Northern Ireland and Germany', NIERC, Research Report 11.

Roper, S and Love, J H (2002a) 'Innovation and Export Performance: Evidence from UK and German Manufacturing Plants', *Research Policy*, 31, 1087-1102.

Roper, S and Love, J H (2002b) 'Innovation and Export Propensity: Panel Evidence for Irish Firms', Working Paper, NIERC, Belfast.

Roper, S Ashcroft, B Love, J H Dunlop, S Vogler-Ludwig, K and Hofmann, H (1996) *'Product Innovation and Development in UK, German and Irish Manufacturing Firms'*, NIERC/Fraser of Allander Institute.

Teece D J, Pisano G and Shuen A (1997) 'Dynamic capabilities and strategic management', *Strategic Management Journal*, 18, 509-533.

Veugelers, R. and Cassiman, B. (1999). Make and buy in innovation strategies: evidence from Belgian manufacturing firms, *Research Policy*, vol. 28, 63-80