The Innovation Value Chain

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Abstract
Innovation events - the introduction of new products or processes - represent the end of a process of knowledge sourcing and transformation. They also represent the beginning of a process of exploitation which may result in an improvement in the performance of the innovating business. This recursive process of knowledge sourcing, transformation and exploitation we call the innovation value chain. Modelling the innovation value chain for a large group of manufacturing firms in Ireland and Northern Ireland highlights the drivers of innovation, productivity and firm growth. In terms of knowledge sourcing, we find strong complementarity between horizontal, forwards, backwards, public and internal knowledge sourcing activities. Each of these forms of knowledge sourcing also makes a positive contribution to innovation in both products and processes although public knowledge sources have only an indirect effect on innovation outputs. In the exploitation phase, innovation in both products and processes contribute positively to company growth, with product innovation having a short-term 'disruption' effect on labour productivity. Modelling the complete innovation value chain highlights the structure and complexity of the process of translating knowledge into business value and emphasises the role of skills, capital investment and firms' other resources in the value creation process.

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The Innovation Value Chain

1. Introduction

An innovation event, such as the introduction of a new product or process, represents the end of a series of knowledge sourcing and translation activities by a firm or partnership. It also represents the beginning of a process of value creation which, subject to the firm's own attributes and market conditions, may result in an improvement in the performance of the innovating business. Knowledge or productivity spill-overs may also then lead to improvements in the performance of other co-related or co-located firms (Klette et al., 2000; Beugelsdijk and Cornet, 2001). Here, however, following Crépon et al. (1998), Lööf and Heshmati (2001 and 2002) and Love and Roper (2001), our focus is on the gains from innovation to the innovating firm itself. Specifically, we are interested in modelling the recursive process through which firms source the knowledge they need to undertake innovation, transform this knowledge into new products and processes, and then exploit their innovations to generate added value. This process we refer to as the Innovation Value Chain (IVC). Knowledge – sourced, transformed and exploited – is the unifying factor which provides the main operational link between the different elements of the innovation value chain. Competitive pressures and opportunities, however, provide the motivation for firms to engage in the risky, uncertain and costly activity which is innovation.

Our view of the IVC comprises three main links, beginning with firms' attempts to assemble the bundle of knowledge necessary for innovation. This may involve firms' in-house R&D activities alongside, and either complementing or substituting for, external knowledge sources (e.g. Pittaway et al., 2004)[1]. Guellec and van

[1] Cassiman and Veugelers (2002), for example, find evidence of a complementary relationship between firms' internal R&D and firms' ability to benefit from external knowledge sources. Other studies, however, have identified a substitute relationship between internal knowledge investments and external knowledge sourcing. Schmidt (2005, p. 14) for example, notes that for Germany 'firms with higher R&D intensities have a lower demand for external knowledge than firms with lower R&D intensities. The more R&D is done in-house the more knowledge is generated internally, and the less external knowledge is required' (see also Love and Roper, 2001).

Pottelsberghe (2004), for example, stress the role of business R&D in shaping firms' ability to absorb and capitalise on external knowledge, while Veugelers and Cassiman (1999) suggest that companies undertaking in-house R&D benefit more from external knowledge sources than companies which have no in-house R&D activity (see also Roper et al., 2000). As Guellec and van Pottelsberghe (2004) and Anselin et al. (1997, 2000) suggest, however, externally acquired knowledge is not homogenous and its complement or substitute relationship with in-house R&D may depend on the type of external knowledge being considered[2]. Following firms' knowledge sourcing activity, the next link in the innovation value chain is the transformation of knowledge into physical innovation. This we model using the standard innovation production function approach (e.g. Geroski 1990; Harris and Trainor 1995; Love and Roper, 1999) which relates innovation outputs (i.e. new products or processes) to knowledge inputs, with the transformational efficiency of the firm linked to the characteristics of the enterprise and its own knowledge and managerial resources. Michie and Sheehan (2003), for example, suggest the importance of firms' human resource management procedures for innovation, while Love et al. (2006) consider the beneficial effects for innovation of organisational factors such as cross-functional teams. The final link in the IVC relates to the exploitation of firms' innovations. This we model using an augmented production function approach (e.g. Geroski et al., 1993).

Our more detailed conceptual framework for the innovation value chain is outlined in Section 2. This emphasises the recursive nature of the causal process we envisage from knowledge sourcing to exploitation and describes in more detail our approach to estimating the different links in the innovation value chain. Section 3 describes our data which relates to manufacturing firms in Ireland and Northern Ireland. Section 4 reports the main empirical findings and Section 5 concludes with a brief review of the key empirical results and the policy and strategy implications. The main empirical innovation in the paper is the ability to identify the impact of different knowledge sources on business performance through the different links in the innovation value

[2] Schmidt (2005), for example, finds that among German firms current in-house R&D has a greater effect on firms' ability to absorb external scientific knowledge than either intra- or inter- industry knowledge flows.

chain.

2. Conceptual Foundations and Modelling Framework

The first link in the innovation value chain is firms' *knowledge sourcing activity*, and we focus in particular on the factors which shape firms' engagement with particular knowledge sources[3]. In earlier papers, for example, we identify five different types of knowledge sourcing activity which might shape firms' innovation activity (Roper and Love, 2005; Roper et al., 2006). First, firms can generate knowledge in-house through investments in in-house R&D, in line with the standard 'make' option in terms of the literature on technology sourcing (Shelanski and Klein, 1995). Second, firms can generate knowledge inputs for innovation through forward linkages to customers. This may reflect either formal or informal knowledge sharing, but provides an indication of the potential importance of, say, knowledge of customers' preferences in shaping firms' innovation success (Joshi and Sharma, 2004). Third, firms can access external knowledge through backward links to either suppliers or external consultants. Horn (2005), for example, emphasises the increasing significance of backward integration in R&D success, while Smith and Tranfield (2005) emphasise the role of such linkages in product rather than process change in the UK aerospace industry. Fourth, we allow 'horizontal' linkages to either competitors (Hemphill, 2003) or through joint ventures. Link et al (2005), for example, identify a range of factors which influence US firms' participation in research joint ventures including levels of public support for research collaboration (the Advanced Technology Programme) and the general level of prosperity in the US economy. Finally, we allow for the development by firms of knowledge linkages to universities or other public research centres (Roper et al., 2004).

In the innovation value chain, we regard firms' decisions about engaging in different

[3] Here, in the literature we find a contrast in the relatively narrow perspective on knowledge acquisiton in some empirical studies of the innovation process, which regard in-house R&D as the only source of knowledge for innovation (e.g. Crépon et al.,1998; Lööf and Heshmati, 2001, 2002), and other more focussed studies which have placed increasing emphasis on different knowledge sources for innovation and the potential complementarities between them (see for example Veugelers and Cassiman,1999; Roper et al., 2005, 2006).

knowledge sourcing activities as simultaneous, and potentially involving significant complementarities or substitutability (e.g. Roper et al., 2006). To allow for potential complementarities or substitutabilities between knowledge sourcing activities we include each knowledge sourcing activity in the models for all other activities. Other factors included in the knowledge sourcing models reflect the characteristics of firms' resource base and operating environment. We argue, following the literature on the resource-based view, that the stronger is a firm's in-house knowledge base the less likely it is to engage in external knowledge sourcing (see also Schmidt, 2005). In the knowledge sourcing models we therefore expect, ceteris paribus, a negative relationship between factors which might proxy the strength of firms' resource base (e.g. enterprise size, foreign ownership, group membership) and the probability of engaging in knowledge sourcing outside the firm. Second, we might expect firms to be more likely to engage in knowledge sourcing outside the enterprise where their absorptive capacity is highest. This will be reflected in high levels of workforce skills (Roper and Love, 2006), or the presence within the enterprise of a strong organisational capacity for undertaking R&D (Zahra and George, 2002). Third, where public support is available to encourage innovation activity, or the upgrading of firms' absorptive capacity, external knowledge sourcing may also be more likely (Roper and Hewitt-Dundas, 2005; Link et al., 2005)[4]. Finally, we also expect a relationship between firms' knowledge sourcing activities and market buoyancy, as Link et al. (2005) find a negative relationship between general levels of prosperity and firms' willingness to participate in research joint ventures in the US. Here, our data covers both Ireland – the Celtic Tiger – and Northern Ireland with the latter having experienced significantly slower growth rates during the 1990s[5]. On the basis of Link et al. (2005) we might therefore expect, ceteris paribus, to observe lower levels of engagement in external knowledge sourcing activity in Ireland.

[4] See Roper and Love (2005) for a detailed account of the development of innovation and R&D policy in Ireland and Northern Ireland during the period covered by the analysis.

[5] For example, average real GDP growth from 1991 to 2000 in Ireland was 7.1 per cent pa compared to 2.7 per cent pa in Northern Ireland. Sources: Ireland, GDP volume growth average measure, Table 13, Budgetary and Economic Statistics, March 2001, Department of Finance; Northern Ireland, NIERC/OEF Regional Economic Outlook, Spring 2001.

To summarise, the probability that firms will engage in each of the five knowledge sourcing activities is given by:

$$KS^*_{jit} = \beta' KS_{kit} + \gamma_0' RI_{jit} + \gamma_1' ACAP_{jit} + \gamma_2' GOVT_{jit} + \gamma_3' MKT_{jit} + \varepsilon_{jit} ,$$

$$KS_{jit} = 1 \text{ if } KS^*_{jit} > 0 ; \; KS_{jit} = 0 \text{ otherwise,} \qquad (1)$$

where; KS_{jit} stands for the i^{th} firm's knowledge sourcing activity *j* (or *k)* at time *t*, and $j,k = 1,2,3,4,5$, $i = 1,......,n$; $t = 1,......,T$. The error term ε_{jit} is assumed to follow a multivariate normal distribution with mean zero and variance-covariance matrix *V*, where *V* has values of 1 on the leading diagonal and $\rho_{jk}=\rho_{kj}$ for $j \neq k$. KS_{kit} represents each firm's other knowledge sourcing activities. If β is positive this would suggest a complementary relationship between firms' knowledge sourcing activities; negative β would suggest a substitute relationship. RI_{jit} is a set of indicators of firms' resource base and, as indicated earlier, we expect γ_0 to be negative. $ACAP_{jit}$ is a set of indicators intended to reflect firms' absorptive capacity and $GOVT_{jit}$ reflect access to government support for innovation and upgrading. Coefficients on both (i.e. γ_1 and γ_2) are expected to be positive. MKT_{jit} is intended to reflect the buoyancy of local markets, and following Link et al., (2005) we expect this to be negative.

To estimate the simultaneous knowledge sourcing equations (1), the most efficient approach from an econometric point of view is multivariate probit (MVP) although, as Greene (2000) p. 616 notes, the efficiency gains from MVP are reduced where the vectors of independent variables are strongly correlated. Here, the anticipated determinants of each knowledge sharing activity are similar (as suggested by equation (1)) with the added potential for simultaneity between knowledge sourcing activities. Further difficulties also arise in the practical application of an MVP approach using our survey based data. First, adopting a simultaneous estimation approach exacerbates the loss of observations due to missing data in our sample, offsetting any gains in statistical efficiency. Second, in practice, achieving convergence with an MVP estimator places some limits on the degree of simultaneity which it is possible to include. In our model this is particularly undesirable because we are interested in the complementary or substitute relationship between knowledge sourcing activities.

Third, the derivation of marginal effects, which are important for our understanding of the innovation value chain, is less straightforward with MVP than with simpler modelling frameworks. Instead of using MVP (on which see Roper et al., 2006) we therefore prefer to adopt a simpler approach using five single equation probit models. This approach, while sacrificing some statistical efficiency, provides substantial gains in terms of the number of observations used, our ability to reflect more fully the relationship between knowledge sourcing activities and our ability to identify readily interpretable marginal effects.

The second link in the innovation value chain is the process of *knowledge transformation,* in which knowledge sourced by the enterprise is translated into innovation outputs. This is modelled using an innovation or knowledge production function (e.g. Geroski 1990; Harris and Trainor 1995) in which the effectiveness of knowledge coordination is influenced by enterprise characteristics, the strength of firms' resource-base, as well as the firm's managerial and organisational capabilities (Griliches, 1992; Love and Roper, 1999). In terms of innovation outputs, we follow the suggestion of Pittaway et al., (2004) who emphasise the importance of examining both product and process innovation. In general terms, we write the innovation production function as:

$$I_{it} = \phi_0{}' KS_{kit} + \phi_1 RI_{it} + \phi_2 ACAP_{it} + \phi_3 GOVT_{it} + \phi_4 MKT_{it} + \varepsilon_{it} \qquad (2)$$

Where I_{it} is an innovation output indicator, k=1,…,5, indicating the alternative knowledge sources identified earlier, ε_{it} is the error term and other variable definitions are as above.

In the innovation production function (equation (2)), however, we have different sign expectations for some of the independent variables from that in the knowledge sourcing equations (equation (1)). Where firms' internal resources are strong, for example, we would expect this to contribute positively to the efficiency with which firms develop new innovations but to discourage knowledge sourcing (e.g. Crépon et al., 1998; Lööf and Heshmati, 2001 and 2002). However, as in the knowledge sourcing models, we expect firms' innovation outputs to be positively related to absorptive capacity (e.g. Griffith et al., 2003). Government assistance too we would regard as contributing to, or augmenting, firms' resource base and would therefore anticipate positive coefficients (e.g. Roper and Hewitt-Dundas, 2005; Link et al., 2005). We also include in the innovation production function locational indicators for whether an establishment is in Ireland or Northern Ireland designed to reflect the legislative and economic environment within which firms are operating. Ceteris paribus more restrictive regulatory environment, for example, might restrict firms' ability to generate new innovation.

The appropriate estimation method for the innovation production function depends primarily on the nature of the dependent variable. Binary indicators for product or process innovation suggest simple bivariate probit models, while innovation success (i.e. the percentage of sales derived from new products) has both upper and lower bounds and suggests Tobit. A potential issue at this stage of the innovation value chain, however, is selectivity bias (e.g. Lööf and Heshmati, 2002). In the innovation production function this may arise from two main sources. First, the group of innovating firms may be self-selecting in some sense inducing a bias between the expected values of the parameters of the estimated innovation production function and the data generating mechanism for the population as a whole. Or, due to sample design, non-response, or survey methodology, the selected sample may be atypical in some way of the underlying population. A consistent estimator for this type of model given standard normality assumptions is the two-stage procedure outlined in Heckman (1979). This involves the estimation of a Probit model to estimate the selection mechanism and the incorporation of a selection parameter in the innovation production function (see Greene, 2005, p. 639 for details). An alternative, more efficient, approach is to use a maximum likelihood estimator for business performance allowing for sample selection. Practical application of both approaches, however, raises issues of identification requiring, ideally, some distinction between the set of variables included in the selection equation and the innovation production function (see Madalla, 1973, p. 271; Cosh et al., 1997). Elsewhere (i.e. Love et al., 2006), we have explored the potential importance of selection bias in the innovation decision using the current dataset. This provided reassuring results, suggesting little evidence of any significant selection bias in the innovation decision, perhaps due to the broadly-based and nationally representative sampling approach used in our survey data and the particular questioning approach adopted[6]. In the estimation of equation (2) reported here we therefore base our analysis on standard econometric approaches, although for comparison we also report additional estimates of equation (2) for innovation success based on the sample of product innovators only (i.e. excluding the lower limit value).

The final link in the innovation value chain is *knowledge exploitation*, i.e. the process by which enterprise performance is influenced by innovation (Geroski et al., 1993). We base our analysis here on an augmented production function including the innovation output measures, firm's market position and internal resource base. In terms of the recursive innovation value chain, we regard innovation outputs as predetermined with respect to business performance in the augmented production function. This is expressed as:

$$BPERF_i = \lambda_0 + \lambda_1 INNO_i + \lambda_2 X_i + \lambda_3 MKT_i + \tau_i \qquad (3)$$

Where $BPERF_i$ is an indicator of business performance (e.g. labour productivity or value-added per employee, sales growth or employment growth), $INNO_i$ includes innovation outputs measures for both process and product innovation, X_i is a set of enterprise specific variables that are hypothesized to affect enterprise performance, and MKT_i is a set of market environment indicators.

[6] For example, non-response surveys conducted after each main survey suggested little evidence of any systematic difference in innovation behaviours between respondents and non-respondents (e.g. Roper and Hewitt-Dundas, 1998, Annex 1). Question non-response was also relatively limited. For example, 91 per cent of respondents indicating they were product innovators (binary response) also provided information on the extent of their innovation activity.

Two main econometric issues arise in operationalising equation (3) – heterogeneity in performance outcomes and potential endogeneity of the innovation output measures. In terms of heterogeneity, it is clear that very large variations can exist in business performance even in narrowly defined industries (see Caves, 1998 for a survey; and on innovation behaviour see Lööf and Heshmati, 2002). To counter the bias introduced by potential outliers we here adopt robust regression approaches to the estimation of the augmented production function (Rousseeuw and Leroy, 1987; Koenker and Bassett, 1978). The potential endogeneity of innovation output measures in models of business performance has been discussed extensively in the literature, and a range of potential approaches have been adopted including two-stage estimation methods (e.g. Crépon et al, 1998) and the simultaneous estimation of the innovation and augmented production functions (e.g. Lööf and Heshmati, 2002). In conceptual terms, however, the recursive nature of the innovation value chain suggests that innovation output measures are necessarily predetermined prior to exploitation; in other words the innovation cannot be exploited until it has been introduced.

3. Data

Our empirical analysis is based on data from the Irish Innovation Panel (IIP) which provides information on the innovation, technology adoption, networking and performance of manufacturing plants throughout Ireland and Northern Ireland over the period 1991-2002. The IIP comprises four linked surveys conducted using similar postal survey methodologies, sampling frames provided by the economic development agencies in Ireland and Northern Ireland, and questionnaires with common questions. Each survey covers the innovation activities of manufacturing plants with 10 or more employees over a three year period with an average survey response rate of 34.5 per cent[7].

Innovation in the IIP is represented by three main variables. First, the proportion of

[7] Details of each wave of the survey can be found in Roper et al. (1996), Roper and Hewitt-Dundas (1998), Roper and Anderson (2000), Roper et al., 2004).

firms' total sales (at the end of each three year period) derived from products newly introduced during the previous three years. This variable – "innovation success" - reflects not only firms' ability to introduce new products to the market but also their short-term commercial success. On average, 15.1 per cent of firms' sales were derived from new products across the IIP (Table 1). The second innovation output measure is a binary indicator of product innovation which reflects the extent of product innovation within the target population. The third innovation output measure is a similar binary indicator of process innovation, an indication of the extent of process innovation within the target population[8]. Over the whole sample, 62.5 per cent of firms were product innovators while 59.2 per cent were process innovators (Table 1). Notably, however, the overlap between the group of product and process innovators was not complete: around 70.2 per cent of product innovators were also process innovators, with 75.3 per cent of process innovators also being product innovators.

Across the panel, the most common form of knowledge sourcing was in-house R&D, being undertaken by 48.2 per cent of establishments (Table 1). In terms of firms' external knowledge sourcing activities the IIP like other innovation surveys suggests that linkages along the supply chain are most common as part of firms' innovation activity - backwards linkages (32.5 per cent) were most common followed by forwards linkages (26.5 per cent). Horizontal linkages (12.1 per cent) and links to public knowledge sources (19.3 per cent), were less common but still formed a potentially important part of the knowledge sourcing strategies of a significant proportion of enterprises.

Our resource indicators are intended to give an indication of the strength of firms' in-house resource base, and its potential impact on knowledge sourcing and innovation. We also allow for the possibility that intra-group knowledge flows may enhance firms' own in-house resources, an issue of particular importance in Ireland (Buckley and Carter, 1999; Love and Roper, 2001). We therefore include variables

[8] For this variable a product (process) innovator was defined as an establishment which had introduced any new or improved product (process) during the previous three years.

which might give a quantitative indication of the scale of firms' resources – e.g. plant size, finance constraints – as well as other factors which might suggest the quality of firms' in-house knowledge base – e.g. multi-nationality, plant vintage, and production type. Multi-nationality is included here to reflect the potential for intra-firm knowledge transfer between national markets and plants, while plant vintage is intended to reflect the potential for cumulative accumulation of knowledge capital by older establishments (Klette and Johansen, 1998), or plant life-cycle effects (Atkeson and Kehoe, 2005).

Absorptive capacity may reflect both the quality of plants' human resource (Freel, 2005) as well as the organisational characteristics of the enterprise (Finegold and Wagner, 1998). In the models we therefore include indicators designed to reflect firms' skills base – the proportion of employees with graduate level qualifications and no qualifications – and whether the plant has a formal R&D department[9].

Literature on publicly funded R&D has suggested repeatedly, since Griliches (1995), that government support for R&D and innovation can have positive benefits for firms' innovation activity both by boosting levels of investment and through its positive effect on organisational capabilities (e.g. Buisseret et al., 1995)[10]. Arguably, this is particularly important in Ireland and Northern Ireland, which during much of the period covered by the IIP enjoyed EU Objective 1 status which provided resources for substantial investments in developing innovation and R&D capability (Meehan, 2000; O'Malley et al., 2006). Indeed, over the sample period we find around a quarter of businesses receiving assistance for innovation, capital investment and/or training during each three year period (Table 1). Finally, to reflect potential differences in the operating environment between Ireland and Northern Ireland we include a locational dummy, and a variable designed to capture any perceived barriers to innovation due to

9 Just under half of the plants which carried out in-house R&D did so using a formal R&D facility (Table 1).
10 Trajtenberg (2001), for example' offers more direct evidence on the links between public R&D support and firms' proprietary knowledge base. In his examination of government support for commercial R&D in Israel operated by the Office of the Chief Scientist (OCS), he concludes that 'industrial R&D expenditures are closely linked (with a reasonable lag) to patents, and so are R&D grants awarded by the OCS'.

regulatory or legislative requirements[11].

4. Empirical Analysis

The complete innovation value chain model is given by equations (1) to (3) below:

$$KS^{*}_{jit} = \beta^{'} KS_{kit} + \gamma^{'}_{0} RI_{jit} + \gamma^{'}_{1} ACAP_{jit} + \gamma^{'}_{2} GOVT_{jit} + \gamma^{'}_{3} MKT_{jit} + \varepsilon_{jit}\,, \quad \text{j,k=1,5}$$

$$KS_{jit} = 1 \text{ if } KS^{*}_{jit} > 0\,; \;\; KS_{jit} = 0 \text{ otherwise,} \qquad (1)$$

$$I_{it} = \phi_{0}^{'} KS_{kit} + \phi_{1} RI_{it} + \phi_{2} ACAP_{it} + \phi_{3} GOVT_{it} + \phi_{4} MKT_{it} + \varepsilon_{it} \qquad (2)$$

$$BPERF_{i} = \lambda_{0} + \lambda_{1} INNO_{i} + \lambda_{2} X_{i} + \lambda_{3} MKT_{i} + \tau_{i} \qquad (3)$$

Discussion of our empirical results follows the recursive structure of the innovation value chain model. Enterprises' knowledge sourcing activities are explored in Section 4.1; Section 4.2 then deals with the innovation production function and considers the determinants of enterprises' decision to innovate and their innovation success. Finally, Section 4.3 focuses on the exploitation link of the innovation value chain. A key focus throughout our analysis is the marginal effect of knowledge sourcing and innovation which determine the strength of the links in the innovation value chain.

4.1 Knowledge Sourcing

The initial link in the innovation value chain is enterprises' knowledge sourcing activity. Bivariate probit models for each of the knowledge sourcing activities are reported in Table 2 based on a pooled sample from the IIP. Two issues are of particular interest here: first, what pattern of complementarity or substitutability exists between enterprises' knowledge sourcing activity; and, secondly, what other factors determine enterprises' knowledge sourcing behaviour.

[11] This derived from a question asking respondents to rank the importance on a Likert scale of regulatory or legislative requirements as a barrier to innovation.

In terms of potential complementarity or substitutability between knowledge sourcing activities, we find strongly significant and positive associations between in-plant R&D and backward knowledge sourcing and public knowledge sourcing. These are illustrated in Figure 1, and suggest a complementary relationship between internal knowledge generation (i.e. in-plant R&D) and some external knowledge sourcing, supporting the results of Cassiman and Veugelers (2002) but running contrary to the results of Schmidt (2005) and Love and Roper (2001) which both suggest a substitution relationship between internal R&D activity and external knowledge sourcing (see also Irwin and Klenow, 1996). Our results on the complementarity of internal and external knowledge sourcing also provide support for the importance of absorptive capacity at the micro-level, reinforcing similar evidence from macro-economic studies (e.g. Griffith et al., 2003; Guellec and van Pottelsberghe, 2004). We also find strong evidence of complementarity between different external knowledge sourcing activities, with forwards and backward knowledge sourcing and backward and public knowledge sourcing being particularly strongly linked (Table 2). One possible explanation is that enterprises are obtaining economies of scope as they learn to manage external relationships effectively and so benefit more from extending the range of their external knowledge sourcing activities.

In terms of the determinants of knowledge sourcing, our results provide some support for the argument that firms' knowledge sourcing strategies are linked to the strength of their internal resource-base (Schmidt, 2005). For example, we find a non linear relationship between plant size and all knowledge sourcing activities except public knowledge sourcing. For in-plant R&D and forward knowledge sourcing (which have little direct linkage – Table 2), the relationship takes an inverted U-shaped suggesting the probability of knowledge sourcing increases with scale below the turning point at 240-280 employees. Conversely, the probability of engaging in backwards and horizontal knowledge sourcing decreases with scale until the turning point (180 employees in the case of backwards knowledge sourcing and 230 employees in the case of horizontal) before increasing again. In substantive terms this suggests that smaller firms are more likely to engage in horizontal or backwards knowledge sourcing but less likely to engage in forward knowledge sourcing or in-plant R&D, a situation which is reversed above the turning points. In more methodological terms, the different impacts of the scale of the enterprise on the probability of each knowledge sourcing activity, a point echoed in Schmidt (2005), emphasises the importance of the disaggregated approach adopted here.

Other resource indicators prove of less general importance but do suggest some important relationships between enterprise characteristics and their knowledge sourcing activities. Multinational firms, for example, are less likely ceteris paribus to be undertaking in-house R&D in our sample, but more likely to be undertaking knowledge sourcing from public sector organisations. This type of linkage may reflect recent suggestions about technology sourcing, where multinational firms invest in certain locations to access technology that is generated by host country firms or universities (Driffield and Love, 2005)[12]. Firms experiencing financial constraints were also more likely to be undertaking knowledge sourcing through in-house R&D from competitors and public knowledge sources than other firms. Here, horizontal links to competitors may reflect the potential for horizontal alliances and joint ventures to allow cost sharing and risk reduction (Irwin and Klenow, 1996), with similar cost considerations also potentially shaping firms' desire to develop links to publicly available knowledge sources.

Absorptive capacity (ACAP) does have some impact on enterprises' knowledge sourcing activities but the links are perhaps weaker, and less general, than might have been anticipated (Table 2). In particular, skill levels within the enterprise prove largely unimportant in shaping external knowledge sourcing, although there is some link to undertaking internal R&D. Enterprises with a formal R&D department were also significantly more likely to be engaged in public knowledge sourcing. These results closely reflect the recent findings of Schmidt (2005) in his analysis of absorptive capacity in German firms. He too finds strong R&D effects on firm' ability to absorb

12 This suggestion may provide another potential motivation for US inward investment, to Ireland over and above more standard accounts based on tax advantages and market access (Ruane and Görg, 1997). But see also Wrynn (1997).

external knowledge but much weaker effects linked to human resources and knowledge sharing routines within the firm. Public support for R&D, innovation and training have a positive impact on both internal R&D and public knowledge sourcing but little consistent effect on enterprises' other knowledge sourcing activities. Enterprises which received public support for product or process development were, in total, 32 per cent more likely to be engaging in in-plant R&D, a result which is consistent with some previous findings (see for example, Griliches, 1995). Public support for R&D or innovation also had a positive effect on the level of public knowledge sourcing which was increased by 6.7 per cent. Some care is necessary, however, in the interpretation of both effects given the potential for selection bias in the award of public support (Maddala, 1993). Finally, market environment effects on firms' external knowledge sourcing behaviour were also weak, although the probability of engaging in R&D in Northern Ireland was significantly lower than that in Ireland, perhaps reflecting firms' lower anticipated level of post innovation returns (Levin and Reiss, 1994).

In summary, we find strong evidence of complementarities between enterprises' knowledge sourcing activities, although these vary considerably in strength (see also Cassiman and Veugelers, 2002). Aspects of enterprises' resource base also prove important but again the relationship to each knowledge sourcing activity differs significantly. Absorptive capacity is perhaps less significant than anticipated, with in-plant R&D playing the most significant role in influencing knowledge sourcing; skill related measures prove less useful. Locational and policy factors also prove important in the analysis reflecting the specificities of firms' operating environment in Ireland and Northern Ireland. Our findings resemble those of Schmidt (2005) for Germany in two important senses. First, our study like his emphasises the different factors which influence knowledge sourcing. Secondly, our study also emphasises in-house R&D capacity and organisation as the key element of ACAP rather than other potential contributors such as skill levels.

4.2 Innovation

The second link in the innovation value chain is the transformation of knowledge into product and process innovation represented by the innovation production function (equation 2). Here, we are interested in the contribution of each knowledge source to innovation as well as in the range of factors contributing to the efficiency of enterprises' knowledge transformation activity. Estimates of the innovation production function for the three innovation output measures are given in Table 3, with column (3) reporting sub-sample estimates for enterprises with non-zero innovation success. Despite the differences in estimation method and dependent variable there are marked similarities between the sign patterns and significance of key variables across the innovation production function estimates. Establishment size, for example, has no impact on product innovation but is significant for process innovation. Likewise plant vintage has a uniformly negative effect, being significant for product innovation success and process innovation. Differences in the estimated models are reflected in Figures 2 and 3 which summarise the key marginal elasticities emerging from the innovation value chain estimation.

Knowledge sourcing of different types has, as expected, a positive impact on innovation where it is statistically significant. In-plant R&D, for example, has a positive and significant effect on both product and process innovation as well as innovation success in the whole sample. Interestingly, however, in-plant R&D has no significant effect on innovation intensity where the model is estimated only for the innovation sub-sample. In substantive terms this suggests that in plant R&D is boosting the likelihood of enterprises engaging in product innovation, but then having no significant impact on the success of that innovation activity. In fact, our estimates suggest that enterprises conducting in-plant R&D are 27.5 per cent and 11.9 per cent more likely to develop product innovation and process innovations ceteris paribus[13]. Together with the results of the knowledge sourcing equations in Table 2, this

[13] In more methodological terms the contrast between the R&D effects in the whole sample and sub-sample models do suggest the potential importance of sample selection bias when estimation is restricted to innovators only. In our sample this approach would have under-estimated the true effect of R&D on increasing the extent of innovation in the population of enterprises.

suggests that in-house R&D contributes to firms' innovation activity in two ways. First, through complementarities, in-house R&D increases the likelihood that firms will engage in external knowledge sourcing, and hence the likelihood that they will be able to obtain successfully the knowledge necessary for innovation. This is an 'absorptive capacity' effect of the sort envisaged by Cohen and Levinthal (1989, 1990), and Zahra and George (2002). Second, in-house R&D contributes directly to enterprises' knowledge stock increasing average innovation intensity - an 'appropriation' effect due perhaps to higher innovation quality.

As expected, forward knowledge sourcing has significant positive influence on both the product innovation decision, increasing the probability of product innovation by 11.2 per cent, and innovation success by (11.1 per cent). Forward knowledge sourcing, however, has no significant process innovation effect, perhaps reflecting the stronger impact of customer-led innovation on product rather than process change (Karkkainen et al., 2001). Conversely, backwards and horizontal knowledge sourcing increase the probabilities of firms' decision to engage in product and process change, but have no impact on innovation success (Figures 2 and 3). This may reflect evidence from Singapore and other countries which emphasises firms' willingness to share process rather than product knowledge as part of collaborative or supply-chain relationships (Tan, 1990; Wong, 1992). Finally, unlike the other knowledge sources, links to public knowledge sources (i.e. universities, public and industry-owned laboratories) have no direct impact on either the probability of process or product innovation, or its success (Figures 2 and 3)[14]. In general terms this result appears contrary to the weight of evidence which suggests that university R&D has positive innovation effects across a range of industries and countries (Mansfield 1995; Jaffe 1989; Adams 1990, 1993; Acs et al 1992, 1994; Fischer and Varga 2003, Verspagen 1999). Indeed, Guellec and Van Pottelsberghe (2004) have suggested that for sixteen OECD countries the productivity gains from investments in public R&D are actually greater than those from private sector R&D. However, it has been argued that in terms of the economic

[14] Public knowledge sourcing does, however, have an indirect positive effect on innovation through its complementary relationship to other types of knowledge sourcing activity (Table 1).

impact of university R&D, Ireland – and also perhaps Northern Ireland – during the 1990s might be considered a special case, with low levels of public and higher education R&D meaning that neither foreign-owned firms or indigenously-owned industry drew significant strength from local higher-education or public institutions (Wrynn, 1997).

Other resources also prove important in shaping enterprises' innovation outputs. Size – as suggested earlier – has no impact on product innovation but does have a positive (and linear) impact on the probability of undertaking process innovation. Plant vintage has a negative effect on the probability that a plant will be a process innovator and also on innovation success, with the percentage of innovative sales declining by around 0.1 per cent for each year a plant ages. This is consistent with a life-cycle model of plant development, which envisages a concentration of innovative activity occurring in the first years after a plant is established, and then declining levels of innovation and increasing product maturity (Atkeson and Kehoe, 2005). Plants focussed on more routinised production also seem more likely to be undertaking innovation in both product and processes than those geared towards bespoke or one-off products. This may reflect the greater managerial sophistication of these plants, or be some aspect of economies of scale in R&D, especially where relatively long runs of fairly settled products give rise to positive returns to process improvements coupled with product improvements. Perhaps more unexpected is the finding that, ceteris paribus, enterprises which are part of multinational groups in Ireland and Northern Ireland are no more likely to be either product or process innovators than other firms. Access to financial resources and external (group R&D) also prove important, with financial stringency encouraging innovation - mater atrium necessitas - and access to group R&D increasing the probability of engaging in product innovation by 8.5 per cent, process innovation by 13 per cent and innovation success by 6.5 per cent.

Absorptive capacity measures also prove important in boosting enterprises innovation outcomes, reflecting the various dimensions of absorptive capacity emphasised by

Zahra and George (2002). High quality human resources contribute strongly to both the product and process innovation decisions and innovation success (e.g. Freel, 2003; Michie and Sheehan, 2002); having a formal R&D department also proves a significant bonus in terms of product innovation success. This latter result emphasises the point that it is not simply the presence within an enterprise of the resources needed for innovation but that their mode of organisation can also make a significant difference to their contribution to innovation.

Government support for innovation also proves important, although as indicated earlier some care is necessary in interpreting the policy implications of this result (Greene, 1997, p. 982). In particular, the coefficients on the policy support – treatment terms – reflect the combination of 'assistance' and 'selection' effects[15]. Finally, it is worthy of note that we identify no locational effect on innovation outputs despite our earlier result of significant locational differences in firms propensity to engage in different types of knowledge sourcing (Table 2).

4.3 From Innovation to Productivity and Growth

The final link in the innovation value chain is the exploitation of enterprises' product and process innovation. The main focus of interest here is the impact of the innovation indicators on business growth and productivity (i.e. value added per employee). Tables 4 and 5 report marginal effects from the estimation of growth and productivity equations with product innovation represented by innovation success and the binary product innovation decision variable respectively.

The first striking result in the performance models is the strongly significant and positive impact of both product and process innovation on business growth in both Tables 4 and 5. The implication is that, regardless of other factors, enterprises which are undertaking either product or process innovation grow faster than those which are

[15] Separately identifying the selection and assistance effects requires a different estimation approach to that adopted here. See Maddala, 1993, pp. 257-290 for a general discussion of the issue and Roper and Hewitt-Dundas (2001) for an application.

not (Figures 2 and 3). The same cannot be said, however, of productivity where we find insignificant process innovation effects and, at least in the innovation success models (Table 4), negative product innovation effects. This result, which has been noted elsewhere[16] (Freel and Robson 2004), we interpret as a disruption effect. For example, the introduction of new products to a plant may disrupt production and reduce productivity, an effect which is also suggested by the negative productivity effects of bespoke production (i.e. one-offs and small batches). Alternatively, the negative productivity effect of innovation success may be explained by a product-lifecycle type effect. In this scenario, newly introduced products are initially produced inefficiently with negative productivity consequences before becoming established and the focus of process innovations to improve productive efficiency.

In addition to the innovation indicators, the strength of enterprises' resource base also proves important in determining performance, although again the importance of different indicators differs somewhat between the productivity and growth models (Tables 4 and 5). Plant size, for example, has a consistent (inverted U) influence on productivity but has no significant impact on either employment or sales growth (e.g. Barkham et al., 1996; Hakim, 1989). The effects of plant vintage also differ, having a positive effect on productivity but consistently negative growth effects. In other words, older plants tend to have higher productivity but slower growth (Roper and Hewitt-Dundas, 2001). Being part of a multi-national group has a similar effect to that of enterprise vintage, positively impacting on productivity but having a negative growth effect. Unsurprisingly too, enterprises with higher capital intensity (per employee) also have higher productivity and tend also to have faster employment and sales growth (Tables 4 and 5). Two other factors also prove consistently important in determining growth and productivity performance. Skill levels have a consistently positive effect on both performance measures, but being located in Northern Ireland is reflected in lower productivity and slower sales and employment growth. In general terms our augmented production function estimates therefore emphasise the

[16] This effect has also been noted with respect to the effect of product innovation on firm-level profitability (Leiponen, 2000)

importance of enterprises' resource base for productivity and growth, but also suggest that innovation has a significant performance augmenting effect.

5. Conclusion

The key results of our estimation are summarised in Figures 2 and 3 which illustrate the innovation value chain using the product innovation decision indicator and the innovation success indicator respectively. In each case, the causal link from knowledge sourcing through innovation to business growth and profitability is clear, although the strength and sign of the different linkages varies depending somewhat on indicator choice. Internal R&D and backwards knowledge sourcing, for example, have positive direct effects on both product and process innovation as well as positive complementarity effects on enterprises other knowledge sourcing activities. Forwards and horizontal knowledge sourcing have similar complementary effects with enterprises' other external knowledge sourcing activities but only have a direct influence on product innovation. Finally, enterprises public knowledge sourcing activities have no direct impact on innovation but have an indirect positive effect on innovation through their strong complementarity with enterprises other knowledge sourcing activities.

In this sense, our analysis suggests an important difference in the routes by which public knowledge sourcing on one hand, and the other types of external knowledge sourcing and internal knowledge sourcing on the other, contribute to innovation and hence business performance. In general terms, this raises some questions about the accessibility of public knowledge generators as innovation partners. In a more specific sense it raises questions about the ability of the university network in Ireland and Northern Ireland to contribute to innovation at least during our sample period[17]. Since 2000, however, and too late to have a significant impact on the current analysis, steps have been taken to strengthen commercially relevant research in universities in Ireland and Northern Ireland. In Ireland, investments under the 2000-06 National

[17] This is despite significant investment during the late-1990s in building connectivity and applied research capability (e.g. the START programme in Northern Ireland and the Programmes for Advanced Technologies (PATs) in Ireland).

Development Plan – including Science Foundation Ireland and the Programme of Research in Third Level Institutions – have increased investment in higher education R&D by an order of magnitude. In Northern Ireland, similarly large investments have been made in developing Centres of Research Excellence. Both may help in the longer-term to strengthen the direct contribution of the higher education sector in Ireland and Northern Ireland to innovation.

In addition to highlighting the direct and indirect routes through which enterprises' knowledge sourcing can influence innovation and business performance, the innovation value chain also highlights the enabling role of other factors in shaping enterprises' knowledge sourcing behaviour and influencing enterprises' knowledge transformation and exploitation capability. The quality of enterprises' human resources, for example, which we interpret here as an indicator of absorptive capacity, influences the innovation value chain through three routes. First, although they have little impact on external knowledge sourcing, high quality human resources do enable internal R&D in our sample of firms (Table 2), and through complementarity effects have a positive effect on firms' other knowledge sourcing activities. Secondly, high quality human resources contribute positively to firms' knowledge transformation ability in both the product and process innovation production functions (Table 3). Thirdly, skill levels contribute to firms' ability to generate value from their innovation, taking strong positive coefficients in both the growth and productivity production functions (Tables 4 and 5). Our innovation value chain analysis allows these different links to be identified explicitly.

In policy terms our innovation value chain analysis has two main implications. First, we are able to clearly identify the drivers of firm-level growth and productivity in Ireland and Northern Ireland, and in particular to highlight the role of capital investment, skills, ownership and innovation. This provides a clear signal that each of these factors is important in influencing innovation and business performance both through their direct effect but also potentially through complementary effects with other innovation drivers. Secondly, through the innovation value chain we are able to identify the drivers of innovation behaviour itself, emphasising the role of R&D as both a direct and indirect influence on innovation success, but also the role of other important sources of knowledge for innovation. The implication is that policy intervention to strengthen knowledge sharing may have direct benefits for innovation, but may also have indirect benefits through complementary relationships with other innovation drivers. Key here is the role of in-house R&D which has both direct benefits and helps to maximise the innovation benefits of other forms of knowledge sourcing.

The richness of the information in the IIP database allows the innovation value chain to be explored in considerable detail for Ireland and Northern Ireland. Our current approach has some limitations, however, which could usefully be addressed in future work. First, although based on panel data we have here adopted a pooled approach to the estimation. This reduces the temporal sophistication of our analysis and the potential to allow for lagged innovation and performance effects. For example, it may be that allowing for lagged product innovation success in the productivity models would suggest a positive impact rather than the negative 'disruption' effect identified in Tables 4 and 5. Future work might examine the dynamics in more detail as new survey data becomes available. Second, our current analysis is limited to Ireland and Northern Ireland. It would be of considerable interest to see whether the type of relationships identified here were robust across national boundaries. Third, in the modelling to date we have employed fairly simple model specifications and estimation approaches. Both could usefully be developed to allow for potential interactions between variables, for example, and to test for the potential impact of selection biases or simultaneity.

Table 1: Summary Statistics

Variable Description	Mean	Std. Dev.
Innovation Indicators		
Innovation success - percentage of new products in sales (%)	15.125	22.842
Product innovation - new or improved products in the previous three years (0/1)	0.625	0.484
Process innovation - new or improved processes in the previous three years (0/1)	0.592	0.492
Knowledge Sourcing Activities		
R&D being undertaken in the plant (0/1)	0.482	0.5
Forward knowledge linkages to clients or customers (0/1)	0.265	0.442
Backwards knowledge linkages to suppliers or consultants (0/1)	0.325	0.468
Horizontal knowledge linkages to competitors or joint ventures (0/1)	0.121	0.326
Public knowledge linkages to universities, industry operated labs or public labs	0.193	0.395
Firm Performance		
Labour productivity (value added per employee)	3.476	0.755
Sales growth	38.197	94.096
Employment growth	20.038	54.574
Resources		
Employment (number)	114.48	315.685
Part of a multi-national enterprise (multinational firms) (0/1)	0.32	0.466
Plant vintage (years)	32.528	30.123
Capital intensity (investments on fixed assets/total employment)	5.886	16.319
Type of production in plant - mainly one-offs (0/1)	0.192	0.394
Type of production in plant - mainly large batches (0/1)	0.294	0.456
Innovation constraints: Shortages of finance (score)	2.812	1.452
Relevant R&D being conducted in the group (R&D in group) (0/1)	0.192	0.394
Absorptive Capacity		
Percentage of workforce with degree (%)	9.064	12.294
Percentage of workforce with no qualifications (%)	46.947	32.369
Formal R&D Department in plant (0/1)	0.213	0.409
Government and EU Assistance		
Government assistance on product/process innovation (0/1)	0.271	0.445
Government assistance on capital (plant/machinery) (0/1)	0.268	0.443
Government assistance on management training/training on process development/best practice (0/1)	0.184	0.388
Market Environment		
Northern Ireland plant (0/1)	0.424	0.494
Legislative/regulatory requirements (score)	2.227	1.277

Source: Irish Innovation Panel

Table 2: Knowledge sourcing equations

Variables	In-plant R&D	Forward knowledge sourcing	Backward knowledge sourcing	Horizontal knowledge sourcing	Public knowledge sourcing
Knowledge sources					
In-plant R&D	-	0.00980	0.0741**	0.00156	0.0607***
	-	(0.030)	(0.034)	(0.016)	(0.020)
Forward KS	0.0215	-	0.528***	0.170***	0.134***
	(0.039)	-	(0.029)	(0.025)	(0.026)
Backward KS	0.0933**	0.472***	-	0.0792***	0.280***
	(0.037)	(0.027)	-	(0.020)	(0.027)
Horizontal KS	-0.0373	0.321***	0.160***	-	0.0590**
	(0.044)	(0.044)	(0.048)	-	(0.026)
Public KS	0.141***	0.197***	0.438***	0.0367*	-
	(0.039)	(0.037)	(0.038)	(0.019)	-
Resource Indicators					
Employment	0.249***	0.177***	-0.148**	-0.0687**	-0.00277
	(0.070)	(0.062)	(0.075)	(0.031)	(0.042)
Employment-squared	-0.0443***	-0.0367***	0.0415**	0.0148**	0.00198
	(0.016)	(0.014)	(0.017)	(0.0067)	(0.0091)
Multinational firms	-0.0618*	-0.00361	0.0361	0.0260	0.0590***
	(0.033)	(0.031)	(0.036)	(0.017)	(0.021)
R&D in group	-0.000649	0.0694**	-0.000856	-0.0178	0.00429
	(0.037)	(0.035)	(0.040)	(0.015)	(0.021)
Shortage of finance	0.0245**	0.0113	-0.00565	0.00902*	0.0108*
	(0.0096)	(0.0090)	(0.011)	(0.0048)	(0.0061)
Absorptive Capacity					
Staff with degree	0.00452***	0.00130	-0.00116	0.0000138	0.00108
	(0.0012)	(0.0011)	(0.0013)	(0.00056)	(0.00069)
Staff with no qualification	-0.000715	0.000537	0.000254	-0.000687***	-0.000205
	(0.00045)	(0.00044)	(0.00050)	(0.00023)	(0.00030)
R&D department	-	-0.00139	0.000342	-0.00700	0.0474*
	-	(0.034)	(0.041)	(0.017)	(0.025)
Government and EU assistance					
Government assistance on product/process	0.320***	0.0299	0.000551	0.0238	0.0682***
innovation	(0.028)	(0.030)	(0.036)	(0.017)	(0.022)
Government assistance on capital	-0.00299	-0.00772	-0.00421	0.00245	0.0328
(plant/machinery)	(0.032)	(0.029)	(0.035)	(0.015)	(0.021)
Government assistance on management	0.0623*	0.0924***	0.0351	0.00828	0.0514**
training/training on process development/best	(0.035)	(0.033)	(0.038)	(0.016)	(0.023)
Market Environment					
Northern Ireland plant	-0.116***	0.0415	0.00413	-0.0212	-0.0242
	(0.028)	(0.027)	(0.031)	(0.014)	(0.018)
Legislative/regulatory requirements	0.0144	-0.00757	0.00415	0.00864	0.00372
	(0.011)	(0.010)	(0.012)	(0.0053)	(0.0069)
Observations	1775	1741	1741	1741	1741
Log likelihood	-996.46	-611.80	-657.67	-512.97	-526.98

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. All the figures in the table are marginal effects generated from probit models. All models include industry dummies.

Table 3: Innovation Production Functions

	Product Innovation			Process innovation: (binary var.)
	Binary variable	Success: whole sample	Success: product innovator only	
Knowledge sources				
In-plant R&D	0.275***	0.1806401***	-0.0206291	0.119***
	(0.027)	(0.02569)	(0.27)	(0.029)
Forward KS	0.112***	0.1109711***	0.0551659***	0.0367
	(0.034)	(0.03054)	(0.007)	(0.038)
Backward KS	0.0811**	0.0329439	-0.0189386	0.160***
	(0.034)	(0.03065)	(0.376)	(0.034)
Horizontal KS	0.0984***	0.0402106	-0.0028787	0.0814**
	(0.037)	(0.03305)	(0.899)	(0.041)
Public KS	-0.0307	-0.0522171	-0.0241271	0.0142
	(0.043)	(0.03325)	(0.296)	(0.042)
Resource Indicator				
Employment	0.000153	0.0000755	0.000019	0.000320***
	(0.00018)	(0.00007)	(0.69)	(0.00012)
Employment-squared	0.00000857	-0.00000142	1.42E-07	-0.00000835
	(0.000034)	(0.000003)	(0.95)	(0.0000075)
Vintage	-0.000237	-0.0015937***	-0.0012434***	-0.000943**
	(0.00045)	(0.00039)	(0.0002569)	(0.00043)
Multinational firms	0.00787	0.0139323	0.002311	0.0240
	(0.029)	(0.02648)	(0.904)	(0.030)
One-off production	-0.123***	-0.1135328***	-0.025847	-0.0570
	(0.037)	(0.03251)	(0.314)	(0.036)
R&D in group	0.0850***	0.0653202**	0.0107255	0.130***
	(0.030)	(0.02867)	(0.593)	(0.032)
Shortage of finance	0.0200**	0.0263102***	0.0135643**	0.00137
	(0.0088)	(0.00799)	(0.017)	(0.0092)
Absorptive Capacity				
Staff with degree	0.00373***	0.0025178**	0.0005818	-0.00400***
	(0.0013)	(0.00105)	(0.42)	(0.0013)
Staff with no qualification	0.0000404	-0.0002872	-0.0004358	0.000111
	(0.00041)	(0.00038)	(0.112)	(0.00043)
R&D department	0.108***	0.0961436***	0.0631407***	-0.00342
	(0.035)	(0.02927)	(0.001)	(0.039)
Government and EU assistance				
Government assistance on product/process innovation	0.0742**	0.0342639	-0.0038481	0.0866***
	(0.030)	(0.02644)	(0.834)	(0.031)
Government assistance on capital (plant/machinery)	0.000572	0.0027234	0.0014553	0.145***
	(0.029)	(0.02547)	(0.935)	(0.028)
Government assistance on management training/training on process development/best practice	0.00771	0.069377***	0.041288***	0.0614*
	(0.034)	(0.02692)	(0.018)	(0.033)
Market Environment				
Northern Ireland plant	-0.00788	-0.0149813	-0.0153116	-0.0484*
	(0.025)	(0.02358)	(0.01731)	(0.027)
Legislative/regulatory requirements	-0.0198**	-0.0115106	-0.0026818	0.00313
	(0.0098)	(0.00901)	(0.681)	(0.010)
Observations	1620	1544	1033	1613
Log likelihood	-752.84	-553.13	-68.57	-882.33

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; All the figures in the table are marginal effects generated from Probit/Tobit models; All models include industry dummies.

Table 4: Augmented Production Function Estimates – Product Innovation Success

	Outlier Robust Regressions			Median Regressions		
	Productivity	Sales growth	Emp growth	Productivity	Sales growth	Emp. growth
Innovation activities						
Innovation success	-0.302***	16.72***	6.747***	-0.285***	28.52***	19.15***
	(0.067)	(2.59)	(1.75)	(0.071)	(2.60)	(1.87)
Process innovation	0.0151	5.256***	3.012***	0.0212	5.521***	2.322***
	(0.030)	(1.14)	(0.78)	(0.032)	(1.15)	(0.83)
Firm Characteristics						
Employment	0.000389***	-0.000609	0.00151	0.000348***	-0.00354	0.00306
	(0.00015)	(0.0053)	(0.0026)	(0.00011)	(0.0052)	(0.0026)
Employment-squared	-0.0000269*	0.0000372	-0.0000677	-0.0000117***	0.000144	-0.000134
	(0.000014)	(0.00045)	(0.00013)	(0.0000037)	(0.00039)	(0.000092)
Vintage	0.00187***	-0.0892***	-0.0836***	0.00140***	-0.0795***	-0.0681***
	(0.00048)	(0.018)	(0.012)	(0.00052)	(0.019)	(0.013)
Capital intensity	0.0179***	0.331***	0.0308	0.0136***	0.209***	0.150***
	(0.0014)	(0.033)	(0.022)	(0.0010)	(0.034)	(0.024)
Multinational firms	0.334***	-7.013***	-4.392***	0.350***	-5.583***	-5.588***
	(0.032)	(1.22)	(0.82)	(0.033)	(1.22)	(0.87)
One-off production	-0.0724*	0.130	0.454	-0.0870**	3.142**	0.526
	(0.039)	(1.50)	(1.02)	(0.041)	(1.51)	(1.09)
Small batch production	-0.0726**	-0.464	0.297	-0.0767**	0.192	-0.224
	(0.028)	(1.10)	(0.75)	(0.030)	(1.11)	(0.80)
Large batch production	0.0136	-1.401	-0.0733	0.0162	-1.087	-0.212
	(0.031)	(1.20)	(0.82)	(0.033)	(1.21)	(0.87)
Absorptive Capacity						
R&D department	0.0359	2.561*	1.899**	0.0327	0.932	0.971
	(0.037)	(1.43)	(0.96)	(0.040)	(1.44)	(1.03)
Staff with degree	0.0122***	0.236***	0.126***	0.0141***	0.358***	0.181***
	(0.0015)	(0.058)	(0.040)	(0.0016)	(0.059)	(0.042)
Staff with no qualification	-0.000704	0.0114	0.00429	-0.000623	0.0232	0.00528
	(0.00047)	(0.018)	(0.012)	(0.00050)	(0.018)	(0.013)
Market Environment						
Northern Ireland plant	-0.121***	-2.866***	-1.991***	-0.117***	-3.549***	-1.689**
	(0.028)	(1.10)	(0.75)	(0.030)	(1.11)	(0.80)
Observations	1681	1674	1677	1683	1675	1677

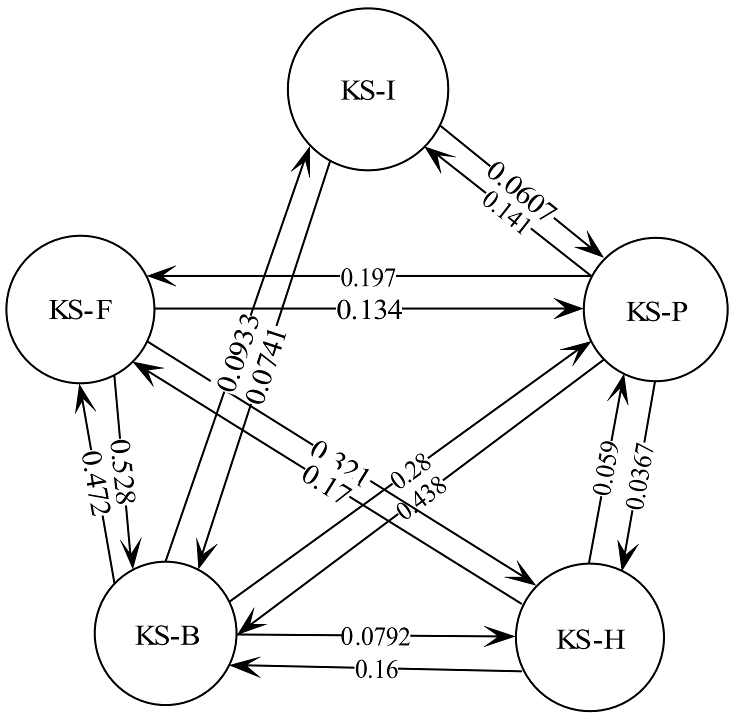
Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. All models include industry dummies.

Table 5: Augmented Production Function – Product and Process Innovation Decision Indicator

	Outlier Robust Regressions			Median Regressions		
	Productivity	Sales growth	Emp growth	Productivity	Sales growth	Emp growth
Innovation activities						
Product innovation	0.0106	3.657***	1.017	-0.00711	4.235***	2.191**
	(0.031)	(1.22)	(0.84)	(0.031)	(1.50)	(0.90)
Process innovation	0.00769	4.863***	3.153***	0.00800	6.104***	3.068***
	(0.030)	(1.15)	(0.79)	(0.029)	(1.42)	(0.85)
Firm Characteristics						
Employment	0.000377**	-0.00157	-0.000666	0.000299***	-0.00555	0.000000255
	(0.00015)	(0.0053)	(0.0034)	(0.00010)	(0.0063)	(0.0026)
Employment-squared	-0.0000248*	0.000103	0.000135	-0.0000101***	0.000333	-0.0000412
	(0.000014)	(0.00045)	(0.00026)	(0.0000033)	(0.00048)	(0.000094)
Vintage	0.00205***	-0.0942***	-0.0874***	0.00145***	-0.0869***	-0.0726***
	(0.00047)	(0.018)	(0.012)	(0.00045)	(0.022)	(0.013)
Capital intensity	0.0167***	0.296***	0.0375*	0.0146***	0.195***	0.164***
	(0.0013)	(0.033)	(0.022)	(0.00093)	(0.041)	(0.024)
Multinational firms	0.330***	-6.916***	-4.022***	0.351***	-5.593***	-5.143***
	(0.031)	(1.20)	(0.82)	(0.030)	(1.48)	(0.87)
One-off production	-0.0590	0.441	0.694	-0.0562	1.409	1.024
	(0.038)	(1.48)	(1.01)	(0.037)	(1.82)	(1.09)
Small batch production	-0.0812***	-0.0867	0.459	-0.0742***	1.381	-0.192
	(0.028)	(1.09)	(0.75)	(0.027)	(1.34)	(0.80)
Large batch production	0.00975	-1.341	-0.151	0.0134	-1.043	0.123
	(0.030)	(1.18)	(0.81)	(0.030)	(1.46)	(0.87)
Absorptive Capacity						
R&D department	-0.000487	2.975**	2.361**	0.0256	4.187**	3.179***
	(0.036)	(1.40)	(0.95)	(0.035)	(1.72)	(1.02)
Staff with degree	0.0113***	0.221***	0.107***	0.0123***	0.389***	0.171***
	(0.0014)	(0.055)	(0.038)	(0.0014)	(0.068)	(0.040)
Staff with no qualification	-0.000566	0.0136	0.00777	-0.000536	0.00568	0.00471
	(0.00046)	(0.018)	(0.012)	(0.00045)	(0.022)	(0.013)
Market Environment						
Northern Ireland plant	-0.118***	-3.060***	-1.970***	-0.0911***	-3.234**	-1.323
	(0.028)	(1.09)	(0.75)	(0.027)	(1.34)	(0.80)
Observations	1751	1746	1747	1753	1747	1748

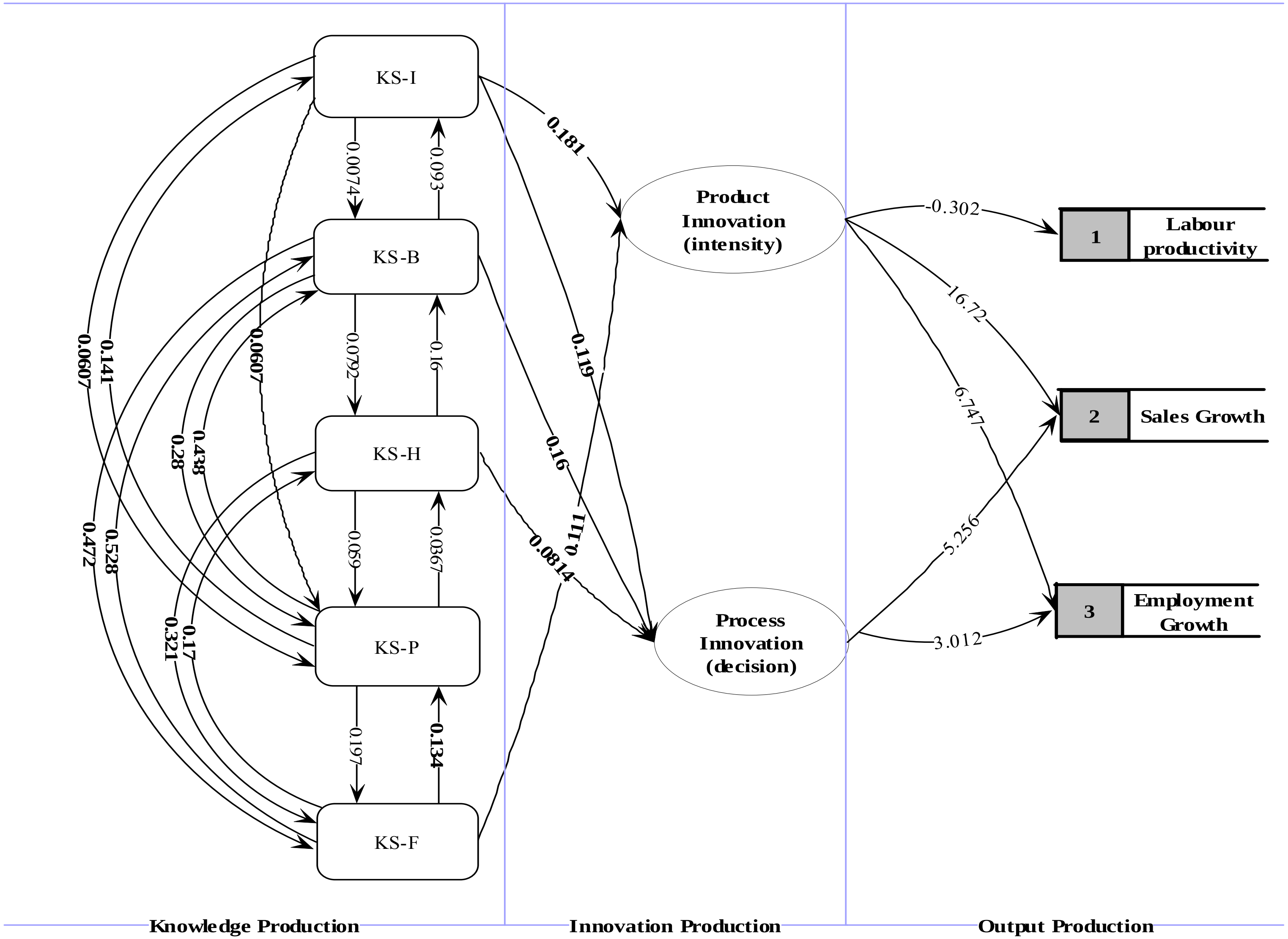
Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. All models include industry dummies.

Figure 1: Links between firms' knowledge sourcing activities



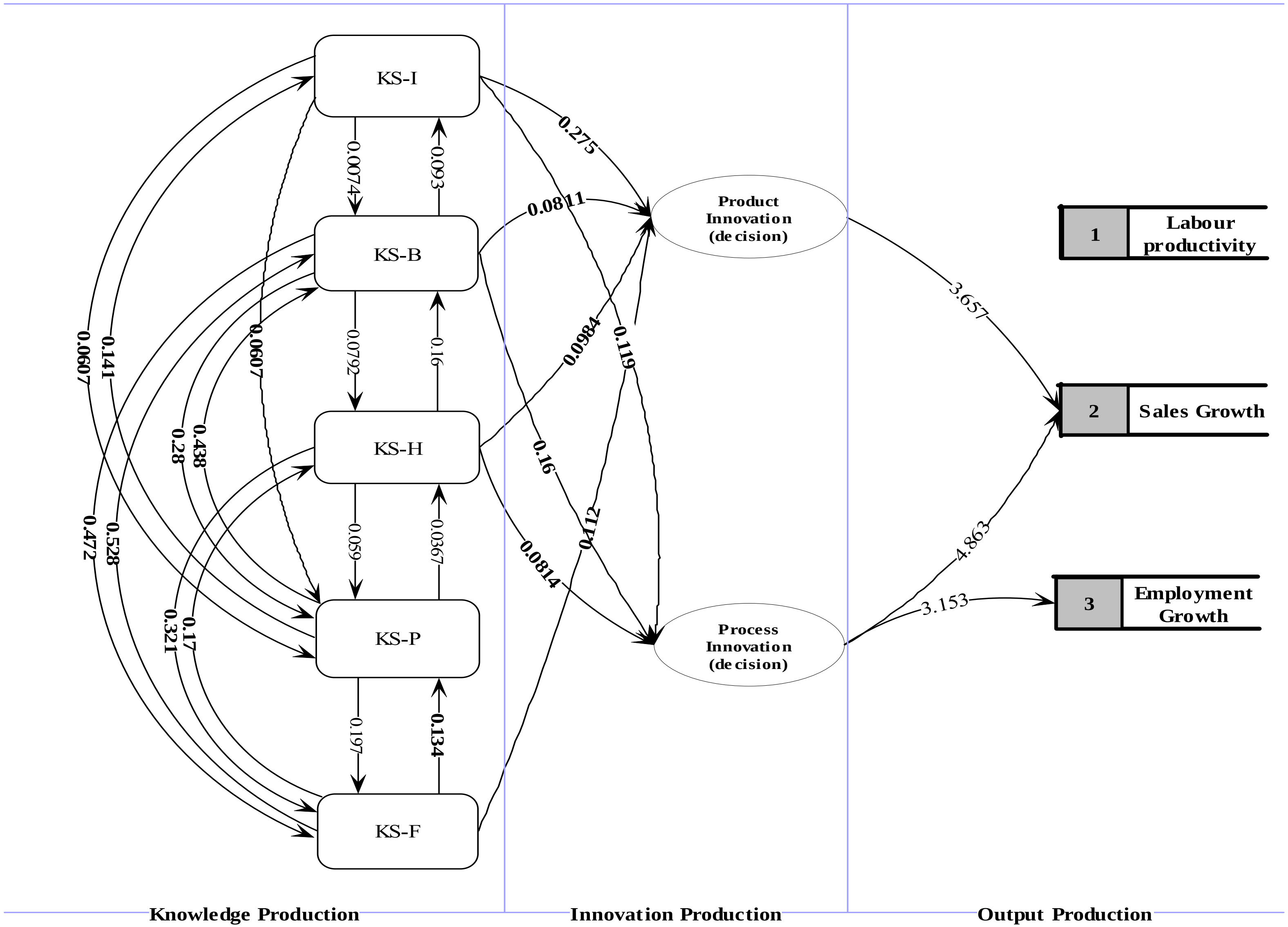
Note: The figures in the chart are marginal probabilities estimated in knowledge sourcing equations (reported in Table 2).

Figure 2: The Innovation Value Chain – Product Innovation Success



Note: The figures are based on outlier robust regression estimates (reported in Table 4).

Figure 3: The Innovation Value Chain - Product and Process Innovation Decision



Note: The figures are based on Ouliter robust regression estimates (reported in Table 5).

References

Acs Z, Audretsch D B and Feldman M P (1992) 'Real effects of academic research: comment', *American Economic Review*, 82, 363-367.

Acs, Z.J., Audretsch, D.B., Feldman, M.P. (1994) 'R&D spillovers and recipient firm size', *Review of Economics and Statistics* 76, 336–340.

Adams J D (1990) 'Fundamental stocks of knowledge and productivity growth', *Journal of Political Economy*, 98, 673-702.

Adams J D (1993) 'Science, R&D, and invention potential recharge: US evidence', *American Economic Review*, 83, 458-462.

Anselin L, Varga A, Acs Z (1997) 'Local geographic spillovers between university research and high technology innovations' *Journal of Urban Economics*, 42, 422-448.

Anselin L, Varga A, Acs Z (2000) 'Geographic and sectoral characteristics of academic knowledge externalities', *Papers in Regional Science*, 79, 435-443.

Atkeson A and Kehoe P J, (2005), 'Modeling and Measuring Organization Capital', *Journal of Political Economy*, 113, 1026–1053

Barkham, R, Gudgin, G, Hart, M and Hanvey, E (1996) *The Determinants of Small Firm Growth: an inter-regional study in the UK 1986-90*, Jessica Kingsley: London

Buckley, P J and Carter, M J (1999) 'Managing Cross Border Complementary Knowledge', *International Studies of Management and Change*, 29, 1, 80-104.

Beugelsdijk S and Cornet M (2001) 'How far do they reach? The localisation of industrial and academic spillovers in the Netherlands', *Centre discussion paper* 2001-47.

Buisseret, T J Cameron, H M and Georgiou, L (1995) 'What Difference Does It Make? Additionality in the Public Support of R&D in Large Firms?', *Evaluation of Research and Innovation*, 10, 4-6, 587-600.

Cassiman, B and Veugelers, R (2002), 'R&D cooperation and spillovers: some empirical evidence from Belgium', *The American Economic Review*, 92, No. 4, 1169-1184.

Caves, R. E. (1998), 'Industrial Organization and New Findings and the Turnover and Mobility of Firms', *Journal of Economic Literature*, 36, 4, 1947-82

Cohen, W.M., Levinthal, D.A. (1989) 'Innovation and learning: the two faces of R&D'. *The Economic Journal*, 99, 569–596.

Cohen, W.M., Levinthal, D.A. (1990) 'Absorptive capacity: a new perspective of learning and innovation' *Administrative Science Quarterly*, 35, 128–152.

Cosh, A D, Hughes, A, Lee, P and Pudney, S (1997) 'Semi-Parametric Estimation of the Company Size-Growth Relationship'. In Begg, I and Henry, S B G (eds) *Applied Economics and Public Policy*, Cambridge University Press.

Crépon, B., Duguet, E., and J. Mairesse (1998) 'Research, Innovation and Productivity: An econometric analysis at the firm level', *Economics of Inovation and New Technology*, 7, 115-158.

Driffield, N and Love J H (2005) 'Who gains from whom? Spillovers, competition and technology sourcing in the foreign-owned sector of UK manufacturing', *Scottish Journal of Political Economy*, 52, 663-686.

Finegold D and Wagner K (1998) 'The Search for Flexibility: Skills and Workplace Innovation in the German Pump Industry', *British Journal of Industrial Relations*, 36, 3, 469-487.

Fischer M M and Varga A (2003) 'Spatial knowledge spillovers and university research: Evidence from Austria', *The Annals of Regional Science*, 37, No. 2, 303 - 322

Freelm M S and Robson, P J A (2004) 'Small firm innovation, growth and performance - Evidence from Scotland and northern England', *International Small Business Journal*, 22, 6, 561-575.

Freel, M S (2005) 'Patterns of innovation and skills in small firms', *Technovation,* 25, 123-134.

Geroski, P. A., (1990) 'Innovation, Technological Opportunities, and Market Structure', *Oxford Econonomic Papers*, 42, 586-602

Geroski P, Machin S, Van Reenen J (1993) 'The Profitability of Innovating Firms', *Rand Journal of Economics*, 24, 2, 198-211.

Greene, W.H. (2005), *Econometric Analysis* (5th ed.). Prentice-Hall, Upper Saddle River, New Jersey.

Griffith, R Redding, S and Van Reenan, J (2003) 'R&D and Absorptive Capacity: Theory and Empirical Evidence', *Scandinavian Journal of Economics*, 105, 1, 99-118.

Griliches, Z (1992) 'The Search For R&D Spillovers', *Scandinavian Journal of Economics*, 94, S29-S47.

Griliches, Z. (1995), ‘R&D and Productivity: Econometric Results and Measurement Issues’, in P. Stoneman (ed.), *Handbook of the Economics of Innovation and Technological Change*, Blackwell, Oxford, 52-89.

Guellec D and van Pottelsberghe B (2004) ‘From R&D to productivity growth: do the institutional settings and the source of funds matter?’ *Oxford Bulletin of Economics and Statistics*, 66, 353-378.

Hakim, C (1989) ‘Identifying Fast Growth Small Firms’, *Employment Gazette*, January, 29-41.

Harris, R. I. D. and M. Trainor (1995) ‘Innovation and R&D in Northern Ireland Manufacuring: A Schumpeterian Approach’, *Regional Studies*, 29, 593-604

Heckman, J (1979) ‘Sample Selection Bias as a specification error’, *Econometrica*, 47, 1, 153-161.

Hemphill, T A (2003) ‘Cooperative Strategy, Technology Innovation and Product Development in Industrial Companies’, *International Journal of Production Economics*, 69, 2, 169-76.

Horn, P M (2005) ‘The Changing Nature of Innovation’, *Research Technology Management*, 48, 6, 28-33.

Irwin, DA and Klenow, P J (1996) 'High-Tech R&D Subsidies - Estimating the Effects of Sematech', *Journal of International Economics*, 40, 323-344.

Jaffe, A. (1989) ‘Real effects of academic research’, *American Economic Review*, 79, 957–970.

Joshi, A W and Sharma, S (2004) ‘Customer Knowledge Development: Antecedents and Impact on New Product Performance’, *Journal of Marketing*, 68, 4, 47-59.

Karkkainen, H Piippo, P Tuominen, M (2001) ‘Ten Tools for *Customer*-Driven Product Development in Industrial Companies’, *The International Journal of Production Economics*, 69, 2, 161-176.

Klette T. J. and F. Johansen (1998), ‘Accumulation of R&D Capital and Dynamic Firm Performance: a not-so-Fixed Effect Model’, *Annales de Economie et de Statistique*, 49/50, 389-419

Klette TJ, Moen J, Griliches Z (2000) ‘Do subsidies to commercial R&D reduce market failures? Microeconometric evaluation studies’, *Research Policy*, 29, 4-5, 471-495.

Koenker, R. and G. Bassett (1978), 'Regression quantiles', *Econometrica*, 46, 33-50.

Leiponen A (2000) ‘Competencies, innovation and profitability of firms’, *Economics of Innovation and New Technology*, 9, 1-24.

Levin, R. and P. Reiss (1984), ‘Tests of a Schumpeterian Model of R&D and Market Structure’, in Z. Griliches, ed., R&D, *Patents, and Productivities*, Chicago: University of Chicago Press

Link, A N Paton, D and Siegel, D S (2005) ‘An Econometric Analysis of Trends in Research Joint Venture Activty’, *Managerial and Decision Economics*, 26, 2, 149-158.

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 A. Heshmati (2002), ‘Knowledge capital and performance heterogeneity: A firm level innovation study’, *International Journal of Production Economics*, 76, 61-85.

Love, J H and Roper, S (2001) 'Location and network effects on innovation success: evidence for UK, German and Irish manufacturing plants”, *Research Policy,* 30, 643-661.

Love JH, Roper S (1999) ‘The determinants of innovation: R & D, technology transfer and networking effects’, *Review Of Industrial Organization*, 15, 1, 43-64.

Love J H, Roper S and Mangiarotti G (2006) ‘Organizing Innovation: Complementarities Between Cross-Functional Teams’, Aston Business School Research Paper 0602, Birmingham.

Maddala, G (1973) *Limited Dependent and Qualitative Variables in Econometrics*, Cambridge University Press, New York.

Mansfield, E., (1995), ‘Academic Research Underlying Industrial Innovations: Sources, Characteristics, and Financing’, *Review of Economics and Statistics*, 77, No. 1, 55-65

Meehan, E. (2000) ‘Britain’s Irish Question: Britain’s European Question?’: British- Irish relations in the context of the European Union and the Belfast Agreement’, *Review of International Studies*, 26, 1, 83-97.

Michie J, Sheehan M (2003) ‘Labour market deregulation, 'flexibility' and innovation’, *Cambridge Journal of Economics*, 27, 1, 123-143.

O’Malley, E, Roper, S, and Hewitt-Dundas, N (2006) ‘Innovation by Invitation; The Irish National Innovaiton System’, in C. Edquist and L.Hommen (eds.), *Small Economy Innovation System:*, *Comparing Globalization, Change and Policy in Asia and Europe*, Elgar (forthcoming)

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

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

Roper S, Ashcroft B, Love J H, Dunlop S, Hofmann H, Vogler-Ludwig K, (1996) ‘Product Innovation and Development in UK, German and Irish Manufacturing’, Queen's University of Belfast/University of Strathclyde/ifo Institut,

Roper, S and Hewitt-Dundas, N (2005) ‘Measuring the Impact of Grant Support for Innovation: Panel Data Evidence for Irish Firms’, European Regional Science Association, Amsterdam, August 2005.

Roper S, 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 Hewitt-Dundas, N and Love, J H (2004) ‘An Ex Ante Evaluation Framework for the Regional Benefits of Publicly Supported R&D Projects’, *Research Policy,* 33, 487-509.

Roper S, Du J and Love, J H (2006) ‘Knowledge sourcing and innovation’**,** Aston Business School Research Paper 0605, Birmingham.

Roper S and Love, J H (2005) ‘Innovation Success and Business Performance - An All-Island Analysis’, All Island Business Model Research Report, InterTradeIreland, July 2005.

Roper, S and Love, J H (2006)’Innovation and Regional Absorptive Capacity: the Labour Market Dimension’, *Annals of Regional Science*, 40, 437-447.

Rosseeuw, P J and Leroy, A M (1987) ‘*Robust Regression and Outlier Detection’*, John Wiley and Sons, New York.

Ruane, Frances and Görg, Holger (1997), ‘The Impact of Foreign Direct Investment on Sectoral Adjustment in the Irish Economy’. *National Institute Economic Review*. 160. 76-86.

Schmidt, T (2005) ‘Absorptive Capacity – One Size Fits All? A Firm-level Analysis of Absorptive Capacity for Different Kinds of Knowledge’, *ZEW Discussion Paper*, 05-72.

Shelanski, H A and Klein, P G (1995) ‘Empirical research in transaction cost economics: a review and assessment’, *Journal of Law, Economics and Organization*, 11, 2, 335-361.

Smith, D J and Tranfield, D (2005) ‘Talented suppliers***?*** Strategic change and innovation in the UK aerospace industry’, *R&D Management*, 35, 1, 37-49.

Tan B. W. (1990) 'Using the supplier relationship to develop the support industry', *Omega- International Journal of Management Science* 18, 151-158.

Trajtenberg, M (2001) ‘Innovation in Israel 1968-1997: a comparative analysis using patent data,’ *Research Policy*, vol. 30, 3, 363-389.

Verspagen B. (1999) ‘European Regional Clubs: Do they Exist and where are they Heading? On Economic and Technological Differences between European Regions’, in J. Adams and F. Pigliaru (eds), *Economic Growth and Change*. Cheltenham: Edward Elgar.

Veugelers, R and Cassiman, B (1999) ‘Make and buy in innovation strtegies: evidence from Belgian manufacturing firms.’, *Research Policy*, 28, 1, 63-80.

Wong P. K. (1992) 'Technological development through subcontracting linkages: evidence from Singapore', *Scandinavian International Business Review* 1(3), 28-40.

Wrynn J (1997) ‘Foreign Direct Investment to a Peripheral Country – The Case of Ireland’ in Fynes, B and Ennis, S (eds) *Competing From the Periphery’* Oaktree Press, Dublin.

Zahra S A and George G (2002) ‘Absorptive capacity: a review, re-conceptualization, and extension’, *Academy of Management Review*, 27, 185-203.