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Knowledge Pathways and Innovation: How do R&D and Skills Enable Knowledge Acquisition from Different Sources?

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Abstract:
Notions of open innovation, and increasing empirical evidence, suggest the importance of boundary spanning links to firms' innovation; while discussion of absorptive capacity has stressed the complementary importance of firms' internal capabilities. Something of a gap exists, however, in our understanding of the specific pathways through which knowledge from different sources, enabled by aspects of absorptive capacity, impacts on firms' innovation outputs. Here, using panel data for Ireland we highlight these knowledge pathways for both product and process innovation. Our results confirm the importance of external knowledge sourcing – from customers, suppliers and links to competitors and joint ventures – for innovation. As in other Irish studies, however, we find no positive effect from links to public knowledge sources. Aspects of firms' capabilities also have positive direct effects on innovation, particularly formal and informal R&D and graduate skills. More surprising is that we find little evidence of complementarities between these two groups of variables in their impact on innovation. For Ireland at least, therefore, the knowledge pathways through which external knowledge sources influence innovation seem largely separate from those of firms' internal capabilities and vice-versa. Our discussion centres on whether the knowledge economy of Ireland has unique characteristics which are shaping this result.

Keywords: Knowledge, Innovation, Absorptive Capacity, Ireland

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1. Introduction

Notions of open innovation (Chesborough 2003, 2006) and the proven importance of external knowledge in increasing firms' innovation success (Love and Roper 2001; Oerlemans, Meeus, and Boekema 1998) have confirmed the importance of boundary spanning links to firms' technological development trajectory. Similarly, discussion of the different dimensions of absorptive capacity since the seminal papers by Cohen and Levinthal (1989, 1990) have stressed the complementary importance of firms' internal capabilities both for absorption and learning. Something of a gap in these literatures, however, has been any very clear understanding of the specific pathways through which knowledge from different sources, enabled by aspects of absorptive capacity, impacts on firms' innovation outputs (although see Schmidt, 2005). Studies by Veugelers and Cassiman (1999), for example, deal with the complementarity of internal and external R&D, reflecting the role of in-house R&D in shaping absorptive capacity (Griffith, Redding, and Van Reenan 2003), but omit any discussion of alternative knowledge sources. These we, and others, have considered extensively elsewhere (Love and Roper 2001) with little discussion of any complementarities with firms' internal knowledge base. Here, our focus is on these knowledge pathways, and on indentifying which specific aspects of absorptive capacity are important in enabling firms to take advantage of each external knowledge source.

Elsewhere we have argued that firms' knowledge sourcing or gathering capability is a crucial link in the innovation value chain linking knowledge inside and outside the firm to innovation and subsequent value creation (Roper, Love, and Du 2008). Different sorts of innovation partners may, however, provide different types of knowledge inputs into the innovation process, requiring different absorptive capabilities. University links, for example, may provide leading edge solutions which can contribute to radical product, process or organisational innovation (Jordan and O'Leary 2007). Absorbing such knowledge is likely to require that firms have strong internal technological capabilities.

Forward linkages to customers on the other hand might provide information on customers' preferences for future innovation or alert the firm to new market opportunities (Joshi and Sharma 2004). Here, CRM technologies and firms' market scanning capabilities may be more important (Kim 1998). Other sources of knowledge for innovation, backward links to either suppliers or external consultants (Horn 2005; Smith and Tranfield 2005), horizontal linkages to either competitors (Hemphill 2003; Link, Paton, and Siegel 2005) or through joint ventures, may also require different knowledge absorption capabilities.

Data for our study is taken from the Irish Innovation Panel which provides information on the innovation activities of Irish manufacturing firms over the 1991 to 2005 period. In Ireland, recent concerns about the absorptive capacity of Irish indigenous firms (Forfas 2005) reflect long-standing concerns about the technological capability of many smaller Irish firms (Wrynn 1997; O'Malley, Roper, and Hewitt-Dundas 2008) and, more specifically, about the benefits of university-business interaction (Jordan and O'Leary 2007). Hopefully, our analysis contributes to this discussion and to wider debates about role of firms' internal capabilities in innovation.

The remainder of the paper is organized as follows. Section 2 summarises previous research on firms' knowledge sourcing for innovation and absorptive capacity as well as the limited number of studies which link the two themes. This leads to hypotheses and a description of our empirical approach based around the notion of the innovation production function. Section 3 discusses our data and econometric approach, and Section 4 summarises the key empirical results. Section 5 reports conclusions and identifies the main policy and strategy implications.

2. Literature and Hypotheses

Since the seminal work of Cohen and Levinthal (1989, 1990) the notion of absorptive capacity has been expanded and developed (Zahra and George 2002). In particular, Zahra and George (2002) offer a useful refinement on the notion of absorptive capacity, developing separate notions of 'potential absorptive capacity' and 'realized absorptive capacity'. Potential absorptive capacity reflects the 'acquisition' and 'assimilation' aspects of ACAP, while 'realised absorptive capacity' incorporates Kim's (1998) notion of firms' 'transformation capability', i.e. firms' capability to develop and refine the routines that facilitate combining existing knowledge with newly acquired and assimilated knowledge. The value of the notion of absorptive capacity is also evident in studies reflecting inter-company knowledge flows. In the context of small and medium enterprises, for example, Liao et al. (2003) find that firms with higher levels of absorptive capacity tend to be more proactive in seeking external knowledge whilst those with more modest absorptive capacity will tend to be more reactive. Following a similar logic, absorptive capacity has been associated with international technology transfers (Keller 2004), while national or regional absorptive capacity has been linked both to the capabilities of individual enterprises as well as that of other knowledge creating or mediating organizations in the region, and the extent of association between organizations (Cooke and Morgan 1998; Narula 2004).

The development of the notion of absorptive capacity has naturally led to some refinement of its measurement. Since (Cohen and Levinthal 1989) the most popular ACAP indicators have been R&D spending, stocks, and intensities (Cassiman and Veugelers 2002). In more recent studies, however, other proxies have been explored relating to firms' use and management of knowledge in R&D and the innovation process. Informal or tacit knowledge, for example, may be an important element of absorptive capacity which can be accumulated through experience (Rosenberg, 1982; Dosi, 1988; Senker, 1995). Romijn and Albaladejo (2002), for example, find that the work experience obtained in either multinational or large domestic firms in the UK by the either the founders or managers of smaller firms has an influence on firms' innovative capabilities. Their results also suggest that work experience in public R&D institutions and a degree in science and engineering have an impact on innovation. This suggests our first hypothesis:

Hypothesis 1: R&D

Both formal and informal aspects of firms' R&D activity may contribute to ACAP and have positive effects on innovation outputs.

More generally, indicators of human capital have played an important role in most discussions of absorptive capacity (Roper and Love 2006). Mangematin and Nesta (1999), for example, argue that firms with highly educated employees will be more effective in their day to day operations as well as more effective in developing external relationships with other individuals with similar competencies outside the firm, facilitating access to external networks of knowledge. This suggests our second hypothesis:

Hypothesis 2: Workforce skills

Workforce skills both at graduate and intermediate levels will contribute to ACAP and will have positive effects on innovation outputs.

The potential for complementarities between the capabilities of the firm and its external collaborations have been illustrated in a number of studies which have suggested the importance of external knowledge sourcing to the success of firms' innovation activity (Veugelers and Cassiman 1999; Cassiman and Veugelers 2002; Love and Roper 2001; Roper, Love, and Du 2008). Externally sourced knowledge may augment or complement firms' in-house knowledge resources, enable learning within the firm and generate economies of scope between knowledge sourcing activities (Roper, Love, and Du 2008). In previous studies (Roper et al 2006; Du et al 2007; Roper et al 2007), we identify four different types of knowledge sourcing activity which, in different contexts, we find to have a significant influence on firms' innovation activity: forward linkages to customers, backward links to either suppliers or external consultants, horizontal linkages to competitors or through joint ventures and public knowledge linkages to either universities or public research centres. Schmidt (2005) argues, however, that the relevant elements of absorptive capacity will differ significantly with respect to the type of external knowledge being sourced by the firm. In particular, for German firms, he finds that R&D intensity has no significant effect on absorptive capacity for intra- and inter-industry knowledge but does have a positive and significant impact on the exploitation of knowledge generated by public research institutions. He also shows that these differences exist with respect to other determinants of absorptive capacity and in particular the share of high-skilled employees. This suggests the potential for different patterns of complementarity between elements of ACAP and external knowledge sources in terms of their contribution to innovation. Specifically, we suggest:

> ***Hypothesis 3: R&D complementarities***
> Firms' internal R&D capabilities will have stronger complementarity with public knowledge sourcing for innovation than other forms of external knowledge sourcing activity.

> ***Hypothesis 4: Skill complementarities***
> Workforce skills will have stronger complementarity with horizontal, forwards and backwards knowledge sourcing for innovation than for knowledge sourcing from public organisations

To test these hypotheses we make use of the now familiar notion of the knowledge production function (Geroski 1990; Harris and Trainor 1995) which relates innovation outputs to knowledge inputs. Here, ACAP provides the link between firms' external knowledge sources and the internal process in which knowledge is transformed or embodied in specific innovations, and our focus of interest is the interaction between the ACAP and knowledge sourcing indicators. The effectiveness of firms' knowledge transformation activity will, of course, also be influenced by other factors including the characteristics of the enterprise, the strength of firms' resource-base, and the firm's managerial and organisational capabilities (Griliches 1992; Love and Roper 1999). This suggests a firm-level knowledge or innovation production function of the form:

$$I = \sum \phi_{0i} ACAP_i + \sum \phi_{1j} KS_j + + \sum \phi_{2ij} KS_j ACAP_i + \phi_3 RI + \phi_4 MKT + \varepsilon$$

Where: I is an innovation output measure, $ACAP_i$ are a series of R&D and skills-based ACAP indicators, KS_j, j=1, 4 are knowledge sourcing indicators, RI is a vector of indictors of firms' resource base, and MKT is a vector of indicators relating to firms' market environment. More specifically, following the suggestion of (Pittaway et al. 2004) we focus on three innovation output measures to capture any differences in knowledge pathways: the probability of undertaking product innovation; the probability of undertaking process innovation, and the percentage of sales derived from innovative products. We use four ACAP indicators intended to reflect firms' formal and tacit knowledge: the presence within the firm of a formal R&D department; other informal R&D within the firm; the level of graduate skills, and the level of intermediate skills.

To allow for the impact of firms' resource base on innovation outputs we include a number of indicators which might give a quantitative indication of the scale of firms' resources, such as plant size. Other factors that might suggest the quality of firms' in-house knowledge base include external ownership, multi-nationality and plant vintage. 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). We also include indicators to reflect the sectoral market in which firms are operating, the time period, whether or not they are located in Northern Ireland and whether or not they received government support for R&D or innovation[1].

3. Data and Methods

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

[1] Literature on publicly funded R&D has repeatedly suggested, 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 organizational capabilities (Buiseret, Cameron, and Georgiou 1995). 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, Roper, and Hewitt-Dundas 2008).

period 1991-2005. More specifically, the IIP comprises five surveys or waves conducted using similar survey methodologies and questionnaires with common questions (Roper 1996; Roper and Hewitt-Dundas 1998; Roper and Anderson 2000). Each of the five surveys covers the innovation activities of manufacturing establishments with 10 or more employees over a three year period and was undertaken by post using a sampling frame provided by the economic development agencies in Ireland and Northern Ireland[2]. The IIP is a highly unbalanced panel reflecting firms' non-response but also the closure and opening of manufacturing units over the 15 year period covered by the panel. The panel itself contains 4525 observations from 2564 establishments and representing an overall response rate of 33.2 per cent (Northern Ireland, 39.1 per cent; Ireland 30.5 per cent).

Three innovation output indicators derived from the IIP are used here. First, the proportion of 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[3]. Over the whole sample, 63.9 per cent of firms were product innovators while 58.2 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.

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[2] 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. The IIP5, conducted between January and June 2006, had an overall response rate of 28.7 per cent.

[3] 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.

The IIP also provides information on firms' linkages to other organisations as part of their innovation activity. Linkages along the supply chain were most common, with 32.2 per cent of firms having backwards linkages and 25.7 per cent having forward linkages (Table 1). Smaller proportions of firms had either horizontal linkages (11.7 per cent) or links to public knowledge sources (17.3 per cent). In terms of ACAP we make use of two R&D measures and two workforce skill indicators (Table 1). 21.3 per cent of firms had a formal R&D unit within the plant with a further 26.8 per cent of firms undertaking R&D but having no such unit. On average around 10 per cent of firms' workforces had a degree while around 27 per cent had a technician or apprenticeship level qualification.

Our econometric approach is dictated largely by the fact that we are using firm level data from two highly unbalanced panels and that our dependent variables – the innovation output indicators – are not continuous[4]. We therefore make use of the GEE (population-average) estimator which provides perhaps the best econometric approach[5]. It enables us to specify the binary character of our variables for process and product innovation, the very right skewed (Poisson) distribution of the innovation sales variable, and obtain heteroscedasticity robust standard errors.

4. Empirical Results

Estimates of the innovation production functions are presented in Table 2-4 for the three innovation output measures: product innovation, product innovation success, and process innovation participation. In each table, column (1) reports baseline estimation results excluding any interaction terms. In models (2)-(5) we then introduce successively the knowledge sourcing-ACAP interaction terms suggested in equation (1); Model (2) includes interactions between the knowledge sourcing indicators and formal R&D; Model (3) includes interactions with informal R&D; Models (4) and (5) include interactions with graduate skills and intermediate skills respectively. For each of the models (2) to (5) we

[4] One might think in applying GLS or GMM estimators. The problem is that our panel is very unbalanced and most of the alternative estimation procedures "balance" the panel if you take into account heteroscedasticity and/or autocorrelation. This results in a tremendous loss of observations.
[5] We use STATA software (xtgee). Stata implementation follows that of Liang and Zeger (1986). For the minimal differences between random effects and population average estimators see Sribney (2007), Neuhaus et al. (1991).

also report Wald tests for the joint significance of the interaction indicators. Throughout the analysis, our main interest is in the interaction of the knowledge sourcing and ACAP indicators but it is useful initially to review the direct impact of each group of measures. For example, forward knowledge sourcing through links to customers and suppliers have, as expected, a positive impact on both the probability of product innovation and its success but weaker effects on process change (Belderbos, Carree, and Lokshin 2006)). Firms with forward links to their customers are around 12-15 per cent more likely to be undertaking product innovation (Table 2), and innovative products are likely to account for 2-6 per cent more of their current sales (Table 3). Backward linkages to suppliers have a more universally positive benefit significantly increasing both the probability of product (+10-12 per cent) and process (+10-18 per cent) innovation and (+5-7 per cent) innovation success. This may reflect evidence from Singapore and other countries which emphasizes firms' willingness to share process rather than product knowledge as part of collaborative or supply-chain relationships (Tan, 1990; Wong, 1992) and the links between process and product innovation. Horizontal linkages to competitors or through joint ventures also had the anticipated positive and significant impacts on both product and process innovation although these were generally smaller than those suggested by the supply-chain linkages (Belderbos, Carree, and Lokshin 2004). Contrary to expectations, however, links to public knowledge sources (i.e. universities, public and industry-owned laboratories) have significant negative effects for both product innovation and success, with positive although insignificant effects on process innovation. These results run contrary to other recent studies from different countries which have suggested positive innovation effects from linkages to public knowledge sources in a very similar analysis (e.g. (Belderbos, Carree, and Lokshin 2004). (Belderbos, Carree, and Lokshin 2006)) and the more general evidence 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)[6]. A negative impact of public knowledge linkages is, however, found in other studies of innovation in Ireland (Jordan and O'Leary 2007) with the suggestion being that this reflects historically low levels of

[6] 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.

higher education R&D in Ireland and relatively weak linkages between Irish firms and universities (Wrynn 1997).

In terms of the ACAP indicators, both formal and informal R&D have the expected positive and significant effects on product innovation (Table 2), innovation success (Table 3), as well as process innovation (Table 4) providing strong support for Hypothesis 1. Interestingly, the magnitude of the coefficients on informal R&D are similar in size to those of formal R&D emphasising the importance of both types of R&D activity in the innovation process (Graziadio and Zawislak 1997). The impact of informal R&D on product innovation success, however, is notably smaller than that of formal R&D (although see Cooper and Kleinschmidt (2007). Graduate skill levels have positive effects on both product innovation and innovation success, in line with the prediction of the classic knowledge utilization capacity theories that more high qualified labour will increase the stock of knowledge of the organization (Mangematin and Nesta, 1999; Vinding 2006). Our results suggest a more surprising negative relationship, however, between graduate skill levels and process innovation although the absolute scale of this effect is very small (Table 4). We also find – contrary to expectations - a negative relationship between levels of intermediate skills and the probability that firms will undertake both product (Table 2) and process innovation (Table 4). There is no evidence that the share of firms' workforce with intermediate skills affects firms' innovation success (Table 3). These results provide only partial support for Hypothesis 2 with the strongest positive link being between graduate skills and innovation success.

Turning to the interaction terms, the Wald tests for joint significance suggest a relatively clear picture – R&D as an element of ACAP is most significant for product innovation and innovation success with the skills elements of ACAP having no significant benefit (Tables 2 and 3). Conversely, for process change, there is no significant interaction with the formal R&D element of ACAP but informal R&D while the two groups of interaction terms involving ACAP skill measures are significant (Table 4). Less clearly anticipated, however, are the signs of some of the interaction effects which do not always suggest the anticipated complementary relationships. More specifically, in terms of product innovation, the coefficients on the interaction terms suggest that the benefits derived from forward, backwards or public knowledge sources are not significantly influenced by the configuration of firms' in-house R&D activities (Table 2). The product innovation benefits derived from horizontal linkages, however, are significantly enhanced where firms have formal R&D activities, and negatively impacted where R&D activities are purely informal (Table 2). Skills aspects of ACAP have almost no significant impact on product innovation (Table 2). In terms of process innovation, the benefits derived from all types of external linkages are unaffected by both formal and informal R&D but the skills aspects of ACAP prove more significant (Table 4). The benefits of forward knowledge linkages in particular, are increased where firms have higher levels of intermediate skills but lower levels of graduate skills. Increasing intermediate skill levels, however, will also have a more negative effect on the process innovation benefits of horizontal knowledge linkages (Table 4). Finally, in terms of product innovation success we see no evidence of positive R&D interactions with external knowledge sources but do see a positive interaction between graduate skills and backwards knowledge linkages (Table 3).

Overall, aside from the suggestion that the R&D elements of ACAP are more important for product innovation and the skills related elements of ACAP are more important for process change, our results provide weak evidence of complementarities between firms' internal capabilities and external knowledge sourcing. External knowledge sources are important, of course, as are internal capabilities for innovation. What our results suggest is that the empirical linkages between the two factors are weaker than might be anticipated from the theoretical discussions of ACAP. This provides little support for Hypothesis 3 or Hypothesis 4 which, following Schmidt (2005) anticipated a clearer contrast between those elements of ACAP linked to different types of knowledge sources.

Other determinants of innovation prove more important with considerable regularity across the different innovation production functions. Establishment size, for example, has a consistent inverted 'U' shape relationship with both product and process innovation (Tables 2 and 4). Similarly, both product and process innovation are significantly influenced by the receipt of government support for innovation, although some care is necessary in interpreting the policy implications of this result (Greene 2005). In particular, the coefficients on the policy support – treatment terms – reflect the combination of 'assistance' and 'selection' effects[7]. Other factors differ in their effect on product and process innovation suggesting the value of the point made by (Pittaway et al. 2004) that both aspects of innovation should be examined. Plant vintage, for example, has no effect on process innovation but a negative and significant impact on product innovation and innovation success. In other words, plants of all ages engage in process change but product innovation is more common and successful in younger plants. This profile 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).

5. Conclusions

Our focus here has been on the relationship between firms' external knowledge sourcing activities for innovation and their internal capabilities reflecting absorptive capacity. As anticipated, external knowledge sourcing – from customers, suppliers and links to competitors and joint ventures – proves a positive and significant influence on both product and process innovation (Oerlemans, Meeus, and Boekema 1998), although as in other Irish studies knowledge sourcing from public knowledge sources proves less helpful for innovation (Jordan and O'Leary 2007). Aspects of firms' capabilities also have positive direct effects on innovation, particularly formal and informal R&D and graduate skills (Roper, Love, and Du 2008). Much less clear in our analysis is any very strong evidence of complementarities (i.e. positive interactions) between these two groups of variables in their impact on innovation. Indeed, aside from the suggestion that the R&D elements of ACAP are more important for product innovation, and the skills related elements of ACAP are more important for process change, our results provide only weak evidence of any complementarities between firms' internal capabilities and

[7] Separately identifying the selection and assistance effects requires a different estimation approach to that adopted here. See Maddala, 1973, pp. 257-290 for a general discussion of the issue and Roper and Hewitt-Dundas (2001) for an application.

external knowledge sourcing. What this suggests is that at least for Ireland the innovation effects of firms' external knowledge sourcing and ACAP are largely independent or additive or, put another way, that these effects are separable in the innovation production function. The knowledge pathways through which external knowledge sourcing therefore influences innovation seems largely separate from that of firms' internal capabilities and vice-versa. Elsewhere, however, we have shown that this is not the case *within* each group of variables with clear evidence of significant economies of scope between different types of knowledge sourcing activity in Irish firms (Roper, Love, and Du 2008).

Our results suggesting the separability of firms' external knowledge sourcing activities and ACAP contrast with other studies which have suggested stronger complementarities between internal investments in R&D and extra-mural R&D activities (Veugelers and Cassiman 1999), and emphasised the role of R&D as an element of ACAP (Griffith, Redding, and Van Reenan 2003). Our results also contrast somewhat with those of Schmidt (2005) who finds clear evidence for German firms that different ACAP attributes are relevant for different external knowledge sources. It may be, of course, that the knowledge economy of Ireland is sufficiently different to that in other European economies to be creating this difference. Inward investment and inward technology transfer to Ireland have inevitably shaped the knowledge ecosystem within which Irish firms operate leading to a somewhat different pattern of knowledge inter-dependencies to that in economies characterised by more endogenous development. This is evident, for example, in much lower levels of association between Irish firms and universities than those in many European economies and in terms of the lack of any very positive innovation effects from university-business interactions noted earlier (Jordan and O'Leary 2007). On the other hand, inward knowledge transfer into Ireland – particularly from the US – is massive compared to that in other comparable countries. From 2003-2006, for example, the value of Ireland's inward technology averaged 989.3 per cent of national R&D spend compared to the next highest OECD countries the Slovak Republic 196.9 per cent and Hungary 193.8 per cent. Other OECD countries had much lower average levels of inward technology flow: Belgium, 77.6 per cent of GERD; Sweden 58.5

per cent; Norway 58.5 per cent; Germany 40.5 per cent; and, Finland 35.7 per cent[8]. For many firms operating in Ireland therefore – particularly those which are members of or suppliers to multinational groups – inward technology transfer or injections of knowledge from outside are therefore likely to be the primary drivers of innovation rather than processes which are more endogenous to the firm. This is likely to be influencing those elements of ACAP which are important in Ireland compared to other countries, reducing the importance of the 'market scanning' elements of ACAP and emphasising the transformational elements. This emphasises the potential value of extending the current study to consider the position in other countries where the scale of inward technology transfer is more typical than that in Ireland.

Our study also relies on a rather conventional set of ACAP indicators – R&D and workforce skills – and other aspects of firms' capabilities may be equally important including internal structures for knowledge sharing and ITC utilisation (e.g. Schmidt, 2005). Other possible extensions therefore relate to the inclusion of such indicators, although we might again expect different ACAP measures to differ in importance in respect to different knowledge sources. Other possible extensions to our study relate to the implicit assumption of a linear relationship between our ACAP indicators and knowledge sourcing measures. Other possibilities include non-linear relationships and hurdle-models where a minimum level of R&D activity or skills are necessary to enable knowledge absorption but subsequent gains are minimal. Both we plan to examine in future work.

[8] Source: OECD MSTI database available at oecd.org accessed 10/2/08.

Table 1: Descriptive Statistics

Variables	Mean	Std. Dev.
Innovation Indicators		
Innovation success - percentage of new products in sales (%)	15.134	22.511
Product innovation - new or improved products in the previous three years (0/1)	0.639	0.480
Process innovation - new or improved processes in the previous three years (0/1)	0.582	0.493
Knowledge Sourcing Indicators		
Forward knowledge linkages to clients or customers (0/1)	0.257	0.437
Backwards knowledge linkages to suppliers or consultants (0/1)	0.322	0.467
Horizontal knowledge linkages to competitors or joint ventures (0/1)	0.117	0.322
Public knowledge linkages to universities, industry operated labs or public labs (0/1)	0.173	0.378
Absorptive capacity Indicators		
Formal R&D: if plant has formal R&D department in plant (0/1)	0.213	0.409
Informal R&D: if plant has R&D but no formal department (0/1)	0.268	0.443
Percentage of workforce with degree (%)	9.696	13.102
Percentage of workforce with a technician or relevant apprentice qualification (%)	27.134	26.338
Control Variables		
Employment (number)	104.916	283.055
Plant vintage (years)	28.259	29.686
Externally-owned plants (%)	0.309	0.462
Part of a multi-national enterprise (multinational firms) (0/1)	0.436	0.496
Northern Ireland plant (0/1)	0.396	0.489
Public support for product innovation (0/1)	0.237	0.425
Public support for process innovation (0/1)	0.151	0.358
Public support for R&D activities (0/1)	0.101	0.302
Time period dummy – 1997 – 1999	0.299	0.458
Time period dummy – 2000 – 2002	0.261	0.439
Time period dummy – 2003 - 2005	0.227	0.419

Source: IIP Waves 2-5.

Table 2: Probit Models for Probability of Product Innovation

	(1)		(2)		(3)		(4)		(5)	
	dy/dx	t-stat.	dy/dx	t-stat.	dy/dx	t-stat.	dy/dx	t-stat.	dy/dx	t-stat.
Knowledge Sourcing Indicators										
Forward knowledge linkages (FKL)	0.130	4.590	0.124	4.380	0.156	4.800	0.148	3.320	0.146	3.560
Backwards knowledge linkages (BKL)	0.123	4.830	0.110	4.170	0.133	4.350	0.109	3.050	0.126	3.440
Horizontal knowledge linkages (HKL)	0.093	2.870	0.062	1.720	0.157	4.760	0.064	1.370	0.161	3.900
Public knowledge linkages (PKL)	-0.107	-2.820	-0.091	-2.140	-0.125	-2.660	-0.090	-1.700	-0.120	-2.120
ACAP Indicators										
Formal R&D in-house	0.281	13.710	0.247	9.560	0.280	13.540	0.282	13.810	0.280	13.670
Informal R&D in-house	0.250	14.390	0.236	14.330	0.282	14.450	0.250	14.370	0.251	14.500
Workforce with degree	0.002	1.640	0.002	1.700	0.002	1.600	0.002	1.510	0.002	1.610
Workforce with technician/apprenticeship	-0.001	-2.620	-0.001	-2.560	-0.001	-2.490	-0.001	-2.620	-0.001	-1.670
ACAP Indicator			Formal R&D		Informal R&D		Graduate Skills		Intermediate Skills	
ACAP x Forward knowledge linkages			-0.012	-0.120	-0.104	-1.410	-0.002	-0.460	-0.001	-0.550
ACAP x Backwards knowledge linkages			0.089	1.260	-0.023	-0.400	0.002	0.480	0.000	-0.060
ACAP x Horizontal knowledge linkages			0.300	24.960	-0.221	-2.720	0.004	0.980	-0.003	-1.870
ACAP x Public knowledge linkages			-0.084	-1.000	0.028	0.410	-0.001	-0.370	0.000	0.300
Control variables										
Employment (number)	0.000	2.380	0.000	2.260	0.000	2.070	0.000	2.350	0.000	2.410
Employment squared (number)	0.000	-1.310	0.000	-1.040	0.000	-0.850	0.000	-1.270	0.000	-1.350
Plant vintage (years)	0.000	-0.560	0.000	-0.510	0.000	-0.520	0.000	-0.590	0.000	-0.530
Externally-owned plants (%)	0.073	2.290	0.068	2.240	0.079	2.500	0.074	2.330	0.075	2.370
Part of a multi-national enterprise (0/1)	-0.002	-0.060	-0.002	-0.070	-0.010	-0.320	-0.002	-0.060	-0.006	-0.190
Northern Ireland plant (0/1)	-0.023	-1.070	-0.023	-1.100	-0.023	-1.090	-0.023	-1.050	-0.023	-1.060
Public support for product innovation (0/1)	0.135	4.630	0.129	4.670	0.136	4.680	0.136	4.710	0.135	4.630
Public support for process innovation (0/1)	-0.018	-0.490	-0.019	-0.540	-0.016	-0.450	-0.019	-0.520	-0.020	-0.560
Public support for R&D activities (0/1)	0.114	3.040	0.113	3.220	0.114	3.050	0.112	2.940	0.115	3.120
Time period dummy – 1997 – 1999	-0.041	-1.610	-0.037	-1.520	-0.043	-1.670	-0.041	-1.620	-0.041	-1.620
Time period dummy – 2000 – 2002	-0.042	-1.590	-0.040	-1.560	-0.044	-1.650	-0.043	-1.620	-0.044	-1.670
Time period dummy – 2003 - 2005	0.051	1.950	0.050	2.050	0.054	2.090	0.050	1.940	0.050	1.940
Observations		2818.00		2818.00		2818.00		2818.00		2818.00
Number of groups		1881.00		1881.00		1881.00		1881.00		1881.00
Equation Wald test ($\chi^2(29)$)	570.100	0.000	634.840	0.000	634.640	0.000	595.840	0.000	570.370	0.000
Interaction Wald test ($\chi^2(4)$)			80.760	0.000	16.880	0.002	1.530	0.822	5.410	0.248

Notes: All models include constant term and ten 2-digit industry dummy variables. **Source**: IIP Waves 2-5.

Table 3: Tobit Models for Product Innovation Success

	(1)		(2)		(3)		(4)		(5)	
	dy/dx	t-stat.	dy/dx	t-stat.	dy/dx	t-stat.	dy/dx	t-stat.	dy/dx	t-stat.
Knowledge Sourcing Indicators										
Forward knowledge linkages (FKL)	4.388	3.210	4.689	2.580	6.718	3.560	6.075	3.500	2.102	1.100
Backwards knowledge linkages (BKL)	7.158	5.230	9.682	5.230	6.993	3.940	5.208	3.160	7.818	3.950
Horizontal knowledge linkages (HKL)	2.526	2.040	1.848	1.070	3.399	2.190	1.402	0.910	4.112	2.110
Public knowledge linkages (PKL)	-4.697	-4.790	-3.629	-2.560	-5.778	-5.040	-3.725	-2.870	-5.219	-3.680
ACAP Indicators										
Formal R&D in-house	16.416	7.680	22.186	8.240	16.020	7.400	16.422	7.680	16.333	7.660
Informal R&D in-house	11.607	7.300	10.897	6.810	13.370	6.860	11.627	7.270	11.542	7.280
Workforce with degree	0.110	3.400	0.101	3.100	0.109	3.340	0.105	2.230	0.112	3.490
Workforce with technician/apprenticeship	0.010	0.540	0.008	0.430	0.012	0.600	0.010	0.510	-0.003	-0.130
ACAP Indicator			Formal R&D		Informal R&D		Graduate Skills		Intermediate Skills	
ACAP x Forward knowledge linkages			-1.091	-0.480	-5.486	-2.870	-0.107	-1.860	0.084	1.690
ACAP x Backwards knowledge linkages			-5.959	-3.360	0.993	0.400	0.133	2.170	-0.019	-0.390
ACAP x Horizontal knowledge linkages			1.077	0.470	-2.351	-1.130	0.078	1.290	-0.057	-1.200
ACAP x Public knowledge linkages			-0.936	-0.470	4.236	1.550	-0.091	-1.470	0.023	0.500
Control variables										
Employment (number)	0.006	2.070	0.007	2.250	0.006	2.000	0.006	2.110	0.006	2.140
Employment squared (number)	-0.001	-1.870	-0.001	-2.020	-0.001	-1.780	-0.001	-1.900	-0.001	-1.860
Plant vintage (years)	-0.106	-4.150	-0.104	-4.080	-0.104	-4.120	-0.105	-4.160	-0.107	-4.160
Externally-owned plants (%)	1.430	0.910	1.823	1.170	1.485	0.950	1.475	0.940	1.511	0.960
Part of a multi-national enterprise (0/1)	1.712	1.160	1.448	1.000	1.526	1.040	1.766	1.190	1.670	1.140
Northern Ireland plant (0/1)	0.006	0.010	0.044	0.040	-0.015	-0.010	-0.065	-0.060	-0.003	0.000
Public support for product innovation (0/1)	3.182	2.600	3.161	2.630	3.202	2.610	3.261	2.670	3.262	2.670
Public support for process innovation (0/1)	-0.064	-0.050	0.151	0.130	-0.111	-0.090	-0.059	-0.050	-0.175	-0.150
Public support for R&D activities (0/1)	4.397	3.220	4.432	3.300	4.322	3.160	4.366	3.180	4.313	3.170
Time period dummy – 1997 – 1999	-0.628	-0.540	-0.665	-0.580	-0.639	-0.550	-0.727	-0.630	-0.578	-0.500
Time period dummy – 2000 – 2002	-1.081	-0.870	-0.875	-0.710	-1.105	-0.900	-1.205	-0.980	-1.060	-0.860
Time period dummy – 2003 - 2005	-0.676	-0.510	-0.681	-0.510	-0.537	-0.400	-0.718	-0.540	-0.663	-0.500
Observations		2672.00		2672.00		2672.00		2372.00		2672.00
Number of groups		1810.00		1810.00		1810.00		1810.00		1810.00
Equation Wald test ($\chi^2(29)$)	738.000	0.000	754.420	0.000	762.630	0.000	775.650	0.000	752.000	0.000
Interaction Wald test ($\chi^2(4)$)			18.260	0.001	11.350	0.000	6.650	0.156	4.870	0.300

Notes: All models include constant term and ten 2-digit industry dummy variables. **Source**: IIP Waves 2-5.

Table 4: Probit Models for Probability of Process Innovation

	(1)		(2)		(3)		(4)		(5)	
	dy/dx	t-stat.	dy/dx	t-stat.	dy/dx	t-stat.	dy/dx	t-stat.	dy/dx	t-stat.
Knowledge Sourcing Indicators										
Forward knowledge linkages (FKL)	0.044	1.450	0.045	1.290	0.065	1.770	0.100	2.770	-0.040	-0.870
Backwards knowledge linkages (BKL)	0.138	5.330	0.149	5.090	0.161	5.180	0.105	3.190	0.180	4.800
Horizontal knowledge linkages (HKL)	0.092	2.670	0.102	2.560	0.144	3.450	0.122	2.830	0.175	3.770
Public knowledge linkages (PKL)	0.023	0.680	0.038	0.900	0.001	0.020	0.020	0.460	0.007	0.130
ACAP Indicators										
Formal R&D in-house	0.148	5.100	0.180	5.180	0.142	4.770	0.147	5.070	0.146	5.010
Informal R&D in-house	0.161	7.330	0.159	7.150	0.199	7.770	0.160	7.260	0.161	7.330
Workforce with degree	-0.002	-2.720	-0.002	-2.740	-0.002	-2.750	-0.001	-1.400	-0.002	-2.780
Workforce with technician/apprenticeship	-0.001	-1.860	-0.001	-1.890	-0.001	-1.770	-0.001	-1.910	-0.001	-1.520
ACAP x Forward knowledge linkages			Formal R&D		Informal R&D		Graduate Skills		Intermediate Skills	
ACAP x Backwards knowledge linkages			-0.010	-0.130	-0.064	-0.980	-0.005	-2.550	0.003	2.560
ACAP x Horizontal knowledge linkages			-0.059	-0.860	-0.067	-1.110	0.003	1.500	-0.002	-1.400
ACAP x Public knowledge linkages			-0.054	-0.630	-0.146	-1.820	-0.002	-0.940	-0.003	-2.340
			-0.023	-0.320	0.045	0.640	0.000	0.030	0.001	0.430
Control variables										
Employment (number)	0.000	3.500	0.000	3.460	0.000	3.440	0.000	3.460	0.000	3.500
Employment squared (number)	0.000	-3.600	0.000	-3.470	0.000	-3.530	0.000	-3.630	0.000	-3.540
Plant vintage (years)	-0.001	-1.800	-0.001	-1.760	-0.001	-1.800	-0.001	-1.830	-0.001	-1.850
Externally-owned plants (%)	0.009	0.250	0.013	0.360	0.011	0.320	0.009	0.270	0.012	0.330
Part of a multi-national enterprise (0/1)	0.080	2.520	0.078	2.450	0.076	2.360	0.079	2.480	0.078	2.460
Northern Ireland plant (0/1)	-0.031	-1.430	-0.030	-1.390	-0.031	-1.460	-0.031	-1.440	-0.032	-1.480
Public support for product innovation (0/1)	-0.018	-0.610	-0.018	-0.580	-0.020	-0.660	-0.017	-0.560	-0.017	-0.560
Public support for process innovation (0/1)	0.248	9.300	0.250	9.380	0.248	9.380	0.247	9.280	0.245	9.110
Public support for R&D activities (0/1)	0.117	3.230	0.116	3.190	0.121	3.370	0.117	3.240	0.116	3.170
Time period dummy – 1997 – 1999	0.044	1.600	0.043	1.570	0.045	1.630	0.042	1.520	0.045	1.640
Time period dummy – 2000 – 2002	-0.002	-0.080	-0.002	-0.070	-0.002	-0.060	-0.003	-0.110	-0.003	-0.100
Time period dummy – 2003 - 2005	-0.014	-0.460	-0.015	-0.500	-0.009	-0.300	-0.014	-0.480	-0.014	-0.460
Observations		2805.00		2805.00		2805.00		2805.00		2805.00
Number of groups		1868.00		1868.00		1868.00		1868.00		1868.00
Equation Wald test ($\chi^2(29)$)	406.860	0.000	428.860	0.000	416.280	0.000	411.490	0.000	405.520	0.000
Interaction Wald test ($\chi^2(4)$)			2.820	0.588	11.090	0.026	8.920	0.063	11.290	0.024

Notes: All models include constant term and ten 2-digit industry dummy variables. **Source**: IIP Waves 2-5.

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