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Learning from open innovation

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Abstract

We explore how openness in one period generates learning effects in the next period which enable firms to be ?better? at open innovation, i.e. to generate more innovation outputs from any given level of openness. Openness to external knowledge sources, whether through search activity or linkages to external partners in new product development, involves a process of interaction and information processing. Such activities are likely to be subject to a process of trial and error, as firms learn which knowledge sources and linkages are most useful to their particular needs, and which partnerships are most effective in delivering innovation performance. Using panel data from Irish manufacturing plants, we find an inverted ?U? shape relationship between the extent (?breadth?) of openness and firms? innovation outputs.

We also find, however, that the shape of this curve depends on prior openness. In other words, learning effects mean that firms which were open innovators in previous periods derive more innovation output from openness in the current period.

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Learning from Open Innovation

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Abstract

We explore how openness in one period generates learning effects in the next period which enable firms to be 'better' at open innovation, i.e. to generate more innovation outputs from any given level of openness. Openness to external knowledge sources, whether through search activity or linkages to external partners in new product development, involves a process of interaction and information processing. Such activities are likely to be subject to a process of trial and error, as firms learn which knowledge sources and linkages are most useful to their particular needs, and which partnerships are most effective in delivering innovation performance. Using panel data from Irish manufacturing plants, we find an inverted 'U' shape relationship between the extent ('breadth') of openness and firms' innovation outputs. We also find, however, that the shape of this curve depends on prior openness. In other words, learning effects mean that firms which were open innovators in previous periods derive more innovation output from openness in the current period.

Key words: open innovation; boundary-spanning linkages; learning effects; Ireland

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1. Introduction

How do firms learn from openness in their innovation activity? There is now a considerable body of literature which supports the idea that openness helps to boost innovation performance, but that there are limits to the beneficial effects of openness (Ahuja 2000; Love and Roper 2001; Katila and Ahuja 2002; Laursen and Salter 2006). We know almost nothing, however, about learning effects in open innovation because most studies of open innovation use cross-sectional data (e.g. Laursen and Salter, 2006). Here, using panel data, we explore how openness in one period generates learning effects in the next period which enable firms to be 'better' at open innovation, i.e. to generate more innovation outputs from any given level of openness. There are good reasons to expect such learning effects. Openness to external knowledge sources, whether through search activity or linkages to external partners in new product development, involves a process of interaction and information processing. Such activities are likely to be subject to a process of trial and error, as firms learn which knowledge sources and linkages are most useful to their particular needs, and which partnerships are most effective in delivering innovation performance. In evolutionary terms, this could be seen as the development of improved open innovation routines (Nelson and Winter, 1982), or from a resource-based perspective the development of new or improved dynamic capabilities (Roper et al., 2008). We therefore anticipate that, the effectiveness of openness in any period will be conditioned by the lessons learned from firms' prior experience of external knowledge gathering and partnering.

Our major contribution here is therefore to provide a dynamic analysis of the firm-level benefits of open innovation with a particular focus on open innovation learning effects. This extends previous cross-sectional analyses – notably that of Laursen and Salter (2006). More specifically, we examine how the existence of prior openness of different types affects the impact which current levels of openness have on innovation performance. Do firms learn more for example, from prior links to suppliers or customers? Or, is it the number of prior linkages which is the most important element of firms' prior experience? We base our analysis on an unbalanced panel of Irish manufacturing plants which covers five successive time periods spanning the 1994-2008 period. We find, like Laursen and Salter (2006), an inverted 'U' shape relationship between the extent ('breadth') of openness and firms' innovation outputs. We also find, however, that the shape of this curve depends on prior openness. In other words, learning effects mean that firms which were open innovators in previous periods derive more innovation output from openness in the current period.

2. Conceptual Framework and Hypotheses

Our central concern here is the way in which firms' open innovation influences their innovation performance, and in particular with how prior levels of openness impact on the relationship between current openness and innovation outcomes. We are also interested, however, in the way in which working with different types of innovation partner may contribute to open innovation learning effects. In terms of the aspects of open innovation highlighted by Dahlander and Gann (2010), we are exclusively concerned with the process of sourcing inbound innovation[1].

The starting point for much of the open innovation literature is the recognition that firms rarely innovate alone. Since the early work of the SAPPHO project (Rothwell et al 1974) and von Hippel's work on the sources of innovation (von Hippel 1998), it has been recognised that innovation cannot be regarded purely as an internal matter: firms' external linkages or networks may also play a potentially important role (Oerlemans, et al., 1998). Numerous studies stress the benefits of boundary-spanning linkages for firms' innovation activity. Financially the role of external linkages increase a firms' ability to appropriate returns from innovation (Gemser and Wijnberg, 1995). Also, Powell (1998) argues that external linkages may help by stimulating creativity, reducing risk, accelerating or upgrading the quality of the innovations made, and signalling the quality of firms' innovation activities. Previous empirical research has also found that participation in collaborations is indicative of an ability for interactive knowledge sharing that may prove very beneficial for further exploitation of knowledge, and thus inter-firm linkages promote innovativeness (Caloghirou, et al., 2002). External links may also be a useful method of searching the technological environment in a systematic fashion, permitting access to improved technology developed elsewhere (Mowery, 1990; Niosi, 1999; Laursen and Salter, 2006). This is not to diminish the part played by a firm's internal resources. The role of R&D in shaping firms' absorptive capacity is now widely recognized (Cohen and Levinthal, 1989; Zahra and George, 2002) suggesting that some internal R&D capacity is needed for three reasons: first, to permit scanning for the best

[1] Dahlander and Gann (2010) classify their review of open innovation literature into four categories: two types of inbound innovation (acquiring and sourcing) and two types of outbound innovation (selling and revealing).

available external knowledge; secondly, to enable the efficient absorption and use of this knowledge; and thirdly, to help in the appropriation of the returns from new innovations (Griffith et al.,2003).

Certain types of boundary-spanning linkages have been examined in detail with respect to innovation, most notable supply-chain linkages (to customers and suppliers), links via alliances and joint ventures, and links to consultants, competitors and to universities and other research establishments. Existing customers can be an excellent source of information to service firms on areas in which their product offerings could be improved, or suggesting new areas of activity which are either not being provided at all, or are currently being provided only (or better) by competitors . As a result, such customer interaction can be the source of both ‘radical’ and improved or imitated products and services . Customers’ involvement in a firm’s innovation process, either formal or informal, has been the subject of considerable research (Preissl, 2000; Bougrain and Haudeville, 2002; Caloghirou, et al., 2002; Joshi and Sharma, 2004; Leiponen, 2005; Tether, 2005; Love and Mansury, 2007; Love et al 2010), with a general consensus that, where it exists, such input is generally favourable to innovation.

Suppliers and their role in the innovation value chain is also an important topic, particularly so due to the often close relationship existing between firm and supplier. This relationship allows for both formal and informal interaction, possibly a hotbed for originating innovative ideas and or suggestions (Hipp, 2000; Hughes and Wood, 2000; Freel, 2000; Bougrain and Haudeville, 2002; Sobrero and Roberts, 2002; Chung and Kim, 2003; Tether, 2005). Horn, 2005, for example, emphasises the increasing significance of backwards integration in R&D success, while Smith and Tranfield (2005) emphasise the role of such linkages in the UK aerospace industry. In their analysis of the innovation value chain, Roper et al (2008) find that links to suppliers are important determinants of firms’ decision to engage in both product and process change.

A firm’s participation in strategic alliances or joint ventures has been widely researched topic. Strategic alliances and joint ventures include activities such as R&D partnerships, collaborative manufacturing, distribution, or complex co-marketing arrangements. The most common rationales offered for corporate partnering and external collaboration involve some combination of risk sharing, obtaining access to new markets and technologies, speeding products to market, and pooling complementary skills (Kogut, 1989; Kleinknecht and Reijnen, 1992; Hagedoorn, 1993; Eisenhardt and Schoonhoven, 1996). Additionally, firms use external relations, such as collaborations, as a temporary mechanism to compensate for capabilities a firm has not yet mastered and to expand all their competencies often by means of vertical integration (Powell, et al., 1996). Specifically for innovation, Linnarsson and Werr (2004) find that some of the challenges of radical innovation could be reduced by engaging in alliances for innovation.

Closely monitoring the competition is an obvious tactic for many business firms, and can be an important source of ideas for new and improved products. Hughes and Wood (2000) report business service firms highly regarding the importance of competitors in the same line of business, and there is evidence that this can lead to innovative behaviour. Hipp (2000), for example, found a positive effect in knowledge-intensive business services (KIBS) which utilise competitors as an external source of innovation, and Leiponen (2005) found that completely new products are most often introduced by firms that engage in external knowledge sourcing particularly from customers and competitors.

With respect to the role of consultancy firms, Hislop (2002) suggests that the development of client–consultancy relations requires to be viewed as an interactive process, with both partners playing an equally important role. Where this is the case, the use of consultancy firms has been shown to be another positive source for innovation (Hughes and Wood, 2000; Hipp, 2000), especially where the firms is considering moving into completely new areas of product or service delivery (Mansury and Love, 2007).

The potential innovation benefits of links to universities and other public research centres have also often been discussed in the literature (Roper, 2004). University-business linkages vary widely ranging from informal relationships, through consultancy-type models to more formal collaborative R&D programmes (Perkmann and Walsh, 2007). In general the evidence point to the crucial role of universities in innovation systems and the positive effect of university-business linkages on innovation both through direct knowledge sharing, through pure knowledge spillovers and through spin-outs.

Using external knowledge, however, also has potential disadvantages. Difficulties assigning intellectual property rights may make external R&D unattractive, as may the lack of appropriate expertise of potential contractors compared to those within a firm's own R&D department. Conversely, under conditions of asymmetric information which will often prevail in the context of research and innovation, a combination of uncertainty and principal-agent type arguments may make external R&D seem more attractive, but can lead to problems of monitoring as the agent is able to exaggerate the costs and commercial potential of their innovations (Audretsch et al, 1996; Ulset, 1996). Even where R&D is not a central feature of innovation, as in much of service sector innovation (Love and Mansury 2007), there may still be limits to the use of external linkages and sources of knowledge. This arises from the capacity of management to pay attention to and cognitively process many competing sources of information, since the span of attention of any individual is limited (Simon 1947). This attention issue means that while the returns to additional linkages or information sources may at first be positive, eventually there will reach a point at which there may be excessive reliance on different external sources of innovation, so that the addition of an additional source actually serves to diminish the returns to external networking at the margin.

Precisely this effect is found by Laursen and Salter (2006) in their analysis of the breadth of information sources used by UK manufacturing firms in innovation. They find that while breadth of information sources enhances innovation, beyond some limit the returns to increased breadth of search become negative. And specifically in the context of external linkages in innovation, Love and Roper (2009) find mixed evidence for the existence of complementarities in the use of external networking between different stages of the innovation process in a sample of UK and German manufacturing plants. In the UK especially, they find strong evidence of substitutability in external networking in different stages, suggesting that there is a limit to the benefits of additional network linkages in innovation.

This discussion of the benefits and drawbacks of external boundary-spanning linkages leads to the first hypothesis:

H1: Innovation performance has an inverted U-shaped relationship with respect to the firm's breadth of boundary-spanning linkages

The role of prior openness

The discussion so far has assumed that openness has a purely contemporaneous effect on innovation performance. In reality, there will be an important temporal dimension to this process: "[O]rganizations often have to go through a period of trial and error to learn how to gain knowledge from an external source. It requires extensive effort and time to build up an understanding of the norms, habits, and routines of different external knowledge channels." (Laursen and Salter, 2006, p. 135). This suggests that there is a learning process involved in open innovation, and that prior openness may have a role to play in shaping the relationship between current levels of openness and innovation outputs.

Two possible mechanisms can be envisaged by which linkages may generate open innovation learning effects. The first mechanism is that enterprises obtain economies of scope as they learn to manage external relationships more effectively. This suggests that there is a certain element of joint production in terms of managing multiple external relationships, with management structures and administration systems capable of carrying out these functions for more than one form of external relationship. For example, similar in-house teams might liaise with different types of innovation partners, thus lowering the cost/and or increasing the return from a given set of relationships. Precisely such a possibility is suggested by the literature on complementarities between different knowledge sources, where strong positive associations and payoffs are found at the firm level between the use of internal and external knowledge sources (Cassiman and Veugelers 2006), and in the use of different external sources (Roper et al 2008). While this is implicitly a static concept, there is the possibility of dynamic economies of scope (Kurdas 1998; Helfat and Eisenhardt 2004) as management teams learn from the process of managing multiple relationships in one period, and are able to apply that learning to more efficiently manage a similar set of different relationships in subsequent periods.

The second mechanism through which open innovation learning effects may be generated is that previous experience of using external knowledge linkages helps to extend the cognitive limits of the management team as they learn to manage more and different forms of innovation linkage. Here, the limit to management's capacity to deal with multiple linkages is not static, but, in a Penrosean sense, exhibits a receding managerial limit as they learn by doing. In this case, through time firms learn to manage a wider range of external relationships before encountering the cognitive limit at which the innovation returns to an additional relationship becomes negative: firms therefore benefit from extending the range of their external knowledge sourcing activities, pushing back the 'limits to openness' identified in Laursen and Salter (2006) and Roper et al (2007).

The joint effect of these two mechanisms suggests there will be learning effects arising from prior openness, leading to our second hypothesis:

H2: Learning effects will mean that the benefits of open innovation will be greater among firms with prior experience of open innovation than among firms with no prior experience.

While in practice the two mechanisms outlined above are likely to occur together, they are conceptually distinct. In the first case (dynamic economies of scope) we expect to find that prior openness leads to increased innovation outputs for any given breadth of external linkages, ,while in the latter case (receding cognitive limit) prior openness allows firms to push back the point at which multiple sources of innovation linkages start to induce decreasing returns with respect to innovation outputs. In practical terms, the first effect implies that the innovation-linkage curve for firms with prior linkages lies above that of firms with no prior linkages, while the second effect implies that range over which there are increasing (innovation) returns to breadth of linkages is greater for firms with prior openness. Whether one or other – or both – of these effects occurs is an empirical issue.

3. Data and Methods

Our empirical analysis is based on data from the Irish Innovation Panel (IIP) which provides information on the innovation activities of manufacturing plants in Ireland and Northern Ireland over the period 1991 to 2008. More specifically, the IIP comprises six surveys conducted every three years using similar survey methodologies and questionnaires with common questions (Roper 1996; Roper and Hewitt-Dundas 1998; Roper and Anderson 2000; Hewitt-Dundas and Roper 2008). Like the Community Innovation Survey, each of the six IIP surveys covers the innovation activities of manufacturing business units over a three-year reference period[2]. The resulting panel is highly unbalanced reflecting non-response in individual surveys but also the opening and closure of business units.

[2] The initial IIP survey, undertaken between October 1994 and February 1995, related to business units' 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 IIP survey was conducted between November 1996

A common feature of the 2nd to 6th waves of the IIP is the following question: *Over the last three years did you have links with other companies or organisations as part of your product or process development?* Plants responding positively to this were then asked to identify the types of external partners with which they were working. Eight potential partner types were identified in the questionnaire: customers, suppliers, competitors, joint ventures, consultants, universities, industry operated laboratories, and government operated laboratories.[3] Reflecting the pattern in most other innovation surveys, the most common partners were customers and suppliers followed by links to consultants and universities. Links to competitors, through joint ventures and industry laboratories were significantly less common (Table 1). In a method analogous to that of Laursen and Salter (2006) on breadth of innovation sources, we use plants' binary responses to each of these eight questions to define an indicator of the breadth of firms' openness with respect to boundary-spanning linkages, which takes values zero to eight depending on the number of different types of innovation partners with which each plant was working. Across the panel as a whole plants were working with an average of 1.1 types of innovation partners, although this varied significantly between plants (coefficient of variation = 1.54) and through time (Table 2 and Figure 1). The share of plants with any external linkages was 39 per cent in 1994-1996 and in 2003-2005, and 46 per cent in 2006-2008. The share of firms with larger number of different types of linkages is significantly lower, only 4 to 10 per cent of plants reported more than 4 external linkages.

There is little evidence, however, of the 'paradigm shift' towards open innovation envisaged in some of the innovation studies literature (see Tables 1-3). Instead what we see is a rather variable – or perhaps cyclical – profile, in which the level of openness (i.e.the breadth of partner types) both for all firms and SMEs varies between IIP surveys (Figure 1). Our data do, however, suggest a clear convergence between the average level of openness in SMEs

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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 IIP 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 fifth wave of the IIP, conducted between January and June 2006, had an overall response rate of 28.7 per cent. The postal element of the sixth wave of the IIP was conducted between April and July 2009 with subsequent telephone follow-up and achieved a response rate of 38 per cent.

[3] Respondents were also asked to indicate whether they had linkages to 'Other group companies'. This type of linkage is excluded from the current analysis on the basis that this linkage is relevant only to firms which are members of groups rather than all firms.

relative to all firms over the 1995 to 2008 period. In Figure 2, for example, we express the mean breadth of openness in SMEs as a proportion of openness in all firms: indicators for all plants and for those with linkages suggest this proportion increased monotonically since 1997-99, suggesting a degree of convergence between the degrees of openness of SMEs and firms in general.

As we have panel data we can, in addition to plants' current breadth of openness, identify whether plants were engaged in open innovation – had any external linkages - in either of the two previous surveys. We use this lagged information to create a dummy variable which takes value 1 if the plant was engaged in open innovation prior to the current period and zero otherwise[4]. This we then use to partition the standard breadth measure between these plants which had and had not undertaken prior open innovation. As is evident from Table 4, plants that had prior linkages had also on average higher number of external linkages in the next periods. Across the panel, production units with prior linkages had on average 1.8 linkages, whereas plants with no prior linkages had on average 0.8 linkages.

As the dependent variable in our analysis we use an innovation output measure: the proportion of the business units' total sales (at the end of each three-year reference period) derived from products newly introduced or improved during the previous three years. This variable reflects not only units' ability to introduce new or improved products to the market but also their short-term commercial success. An average of 21.9 per cent of sales was derived from either newly introduced or improved products (Table 4). Over the sample around 63 per cent of plants reported introducing a new or improved product

The IIP also provides information on a number of other plant characteristics which previous studies have linked to innovation outputs. For example, whether or not plants are under-taking in-house R&D may be important in providing the knowledge inputs for innovation (Crépon et al. 1998, Oerlemans et al 1998; Love and Roper 2001; Jordan and O'Leary 2007), and shaping absorptive capacity (Griffith et al 2003). Across the panel, in-house R&D was

[4] In the first component survey of the IIP relating to 1991-93 the question relating to firms' external linkages for innovation takes a different form to that in later surveys. Here firms were asked to 'indicate which stages of the product innovation process have typically been undertaken in this plant or whether another company or organisation has been involved'. Respondents were then asked to indicate whether any external relationship was with another group company or through a collaborative or sub-contract relationship in seven specific elements of the innovation process. For this survey we let the prior OI dummy to value one where a plant engaged in either a collaborative or sub-contract relationship in any element of the innovation process.

being undertaken by 47 per cent of business units (Table 4). Other resource indicators are included to capture the potential impact on innovation of the strength of plants' internal resource base. We include variables which might give a quantitative indication of the scale of units' resources – e.g. employment – as well as other factors which might suggest the quality of business units' in-house knowledge base – e.g. multinationality and vintage.

Multinationality is included here to reflect the potential for intra-firm knowledge transfer between national markets and business units (O'Sullivan 2000, Dunning 1988, Lipsey 2002), while vintage is intended to reflect the potential for cumulative accumulation of knowledge capital by older business units (Klette and Johansen 1998) or life-cycle effects (Atkeson and Kehoe 2005). We also include a variable reflecting the proportion of each business unit's workforces which have a degree level qualification to reflect potential labour quality impacts on innovation (Freel 2005; Leiponen 2005) or absorptive capacity. Finally, studies of the impact of publicly funded R&D have, since Griliches (1995), repeatedly suggested that government support for R&D and innovation can have positive effects on innovation activity both by boosting levels of investment (Hewitt-Dundas and Roper 2009) and through its positive effect on organisational capabilities (Buiseret et al 1995). Here, we therefore include dummy varibles to indicate a range of public investments in business units' technological and human resources, largely due to the EU Objective 1 status of Ireland through much of the sample period (Meehan 2000; O'Malley et al 2008).

We estimate two forms of the innovation production function. Let IO_{it} be an innovation output indicator (for plant i at survey period t) and FCB_{it} be the vector of plant characteristics which we use to control for other influences on innovation outputs. The first form, which provides benchmark estimates, is a standard innovation production function incorporating breadth and breadth-squared variables analogous to Laursen and Salter (2006). Let OI_{it} represent the breadth of plants' open innovation activity (i.e. count of different types of external linkages), then this innovation production function with sector specific effects (λ_j) and time effects (τ_t) can be written as:

$$IO_{it} = \delta_0 + \delta_1 OI_{it} + \delta_2 OI_{it}^2 + \delta_3 FCB_{it} + \lambda_j + \tau_t + \varpi_{it}\,. \qquad (1)$$

Here, i denotes the plant, t period (IIP wave), and j sector (at 2-digit level). Hypothesis 1 implies that $\delta 1>0$ and $\delta 2<0$, reflecting the inverted 'U' shaped relationship between innovation outputs and breadth.

To capture potential learning effects and test for Hypotheses 2 (as outlined in Section 2) we then partition both OI_{it} and its square between firms that engage in prior openness and those and that do not. Let PR_{it} take value 1 if a plant engaged in prior OI and value 0 otherwise then (1) can be rewritten as:

$$IO_{it} = \delta_0 + \delta_{11} PR_{it} xOI_{it} + \delta_{12}(1 - PR_{it})xOI_{it} + \delta_{21} PR_{it} xOI_{it}^2 + \delta_{22}(1 - PR_{it})xOI_{it}^2 + \delta_3 FCB_{it} + \lambda_j + \tau_t + \varepsilon_i \quad (2)$$

We can test Hypotheses 2 based on the coefficients $\delta 11$, $\delta 12$, $\delta 21$ and $\delta 22$ from Equation (2). H2 states that: f*irms with prior boundary-spanning linkages experience higher innovation returns to their current linkages than those without prior linkages.* Clearly if the coefficients of the variables $PR_{it} xOI_{it}$ and $(1 - PR_{it})xOI_{it}$, and those of their squared, terms, are not significantly different from each other, then the relationship between innovation and current linkages does not depend on prior openness. Therefore we reject H2 if we cannot reject the joint equality test of $\delta 11 = \delta 12$ and $\delta 21 = \delta 22$.[5]

Since $\delta 11 > \delta 12$ is a necessary but not sufficient condition for an upward shift of the 'prior' curve relative to the 'no prior' curve (the squared terms are also relevant[6]), a crucial test of H2 is the test for the following conditions: $\delta 11 > \delta 12$ and $\delta 21 = \delta 22$. If these tests cannot be rejected, the 'prior' curve unambiguously lies above that of the 'no prior' curve, and the former may also have a turning point to the right of the latter. This implies that firms with prior boundary-spanning linkages do indeed experience higher innovation returns to their current linkages than those without prior linkages, and provides support for H2. In such a case visual inspection of the relevant curves indicates whether just one or both of the possible mechanisms for the effect of prior openness is in operation.

[5] Strictly, H2 is also rejected if $\delta 11 < \delta 12$, but this does not arise empirically in any case (see results).
[6] It is technically possible for $\delta 11 > \delta 12$ to occur without an upward shift of the 'prior' curve if $|\delta 21| > |\delta 22|$.

Our estimation approach is dictated largely by the nature of a dependent variable that can take values from 0 to 100, and by the fact that we are using business unit data from a highly unbalanced panel. Therefore we employ a panel data tobit model in estimating Equations (1) and (2). Among the control variables we also include in each model a set of sector controls at the 2- digit level and a series of time dummies to pick up any secular differences and differences between the component surveys of the IIP. Observations are also weighted to provide representative results and take account of the structured nature of the IIP surveys.

4. Results

The results of estimating Equations (1) and (2) are given in Tables 5 and 6 and are described graphically in Figures 3–5. The dependent variable in our analysis is the share of new and improved products[7] in sales. Because this particular type of dependent variable is restricted between values of 0 and 100, we employ a Tobit regression model.

Model 1 in Table 5 investigates the specification of the knowledge production function analogous to that used in Laursen and Salter (2006), with current breadth of linkages and its squared term as the key explanatory variables. As evident from the statistically significant coefficient of the current number of linkages, the breadth of knowledge linkages is an important determinant of innovation output of manufacturing plants in Ireland. The non-linear relationship is confirmed by the significant parameter for the squared term of the external knowledge linkages. We therefore find support for Hypothesis 1, that innovation output has an inverted U-shaped relationship with plant's breadth of boundary-spanning linkages. Apparently, once a particular level of boundary-spanning linkages is present, the knowledge linkages provide decreasing returns for innovation performance. The tipping point in this relationship is around 5 or 6 linkages (see Figure 3A): beyond this number of linkages there are decreasing returns to increasing 'breadth' of linkages. Potentially, this may be due to the costs of 'over-searching' (see e.g. Koput 1997, Laursen and Salter 2006): the lack of absorptive capacity to benefit from a large number of linkages, wrong timing of introduction of new linkages, lack of depth of managerial attention to some particular important ideas and linkages (i.e. too much diffusion of managerial attention across different linkages). Note,

[7] We have also implemented robustness tests with the share of new products in sales and the product innovation dummy as alternative dependent variables. These results confirm the main findings in Table 1 and 2 and are available upon request.

however, that since only a tiny fraction of plants employ five or more types of linkages in any of the observed time periods (see Table 2), this suggests a strong degree of sub-optimal linkage development among the sampled firms.

The coefficients of other control variables in the knowledge production function are largely unsurprising. Their coefficients are in accordance with findings in other papers estimating the knowledge production function (Crépon et al. 1998, Griffith et al. 2003, Roper et al 2008). We find that firms that conduct R&D report on average 29.7 percentage points higher share of sales of new and improved products than the rest, also government support in product development process, foreign ownership and firm size are positively associated with innovation performance of firms. By contrast, age is negatively associated with innovation output, suggesting younger plants tend to be more innovative in terms of the proportion of new and improved products in their portfolio. Firms in Northern Ireland have lower innovation performance (see Northern Ireland dummy) than these in the Republic of Ireland, even after accounting for industry specific effects, size differences and a number of other controls.

We next investigate whether the presence of prior openness changes the effects of current boundary-spanning linkages on innovation output of the plant (Hypothesis 2). This is done by decomposing the effect of current boundary-spanning linkages between firms that have prior external linkages and these that do not and re-estimating the innovation production function, as indicated by equation (2). This analysis of the role of prior linkages is the main contribution of our paper to the existing literature on open innovation. The effects of current openness, depending on whether the plant had external knowledge linkages in previous periods, are shown in Models 2, 3 and 4 in Table 5, and for specific types of prior linkages in Models 5, 6 and 7 in Table 6. The parameter estimates from these different specifications yield consistent results. They all show an inverse U-shaped relationship between the current openness and innovation performance. However, an important finding based on different specifications is that the particular level of prior openness matters in determining the benefits of current boundary-spanning linkages.

Model 2 in Table 5 estimates the main specification of the Equation (2), where the prior openness indicator is equal to 1 if the plant had any external knowledge linkages in at least one of the two previous waves of the survey.   The inverted U-shaped relationship is again evident both for firms which have and do not have prior boundary-spanning linkages: graphically, this is depicted in Figure 3B, where the curve for firms with prior linkages lies above and to the right of those with no prior linkages. However, the formal test of H2 requires that we are able to reject the joint hypothesis that $\delta 11 = \delta 12$ and $\delta 21 = \delta 22$: the Wald test for this joint restriction has a p-value of 0.169, suggesting that we cannot reject the null hypothesis that the two curves are statistically equivalent. Therefore, despite appearances from Figure 3B, we are unable to find unambiguous support for Hypothesis 2

However, it may be the case that plants need to reach a certain level of prior openness before the beneficial effects materialise. This is tested in Models 3 and 4 in Table 5, where correspondingly, the prior openness dummy is equal to 1 if the plant had at least 3 or 4 knowledge linkages respectively during at least one of the two previous periods. The results again point to the non-linear effects of current openness, suggesting further support for H1. Moreover, there is some statistical evidence of the significant role of prior openness in these effects. The curves showing the effects of current openness 'with prior openness' and 'without prior openness' are shown in Figure 4A and 4B. In both cases having prior knowledge linkages is associated with an upward shift in the curve that depicts the relationship between current boundary spanning linkages and innovation. However, the formal Wald tests of the joint condition that $\delta 11 = \delta 12$ and $\delta 21 = \delta 22$ in Equation (2) is rejected statistically only in the case of Model 3 (i.e. 3-plus linkages in a prior period)[8]. Therefore H2 is rejected in the case of 4-plus linkages. In the 3-plus case (Model 3), Wald test also indicates that $\delta 11 > \delta 12$ and $\delta 21 = \delta 22$, suggesting not only that the 'prior' and 'no prior' curves are different, but that H2 cannot be rejected. Firms with 3-plus prior linkages have a significantly greater return to their current linkages than firms without prior linkages. Visual inspection of the relevant curves (Figure 4A) shows that this effect arises from an upward shift of the curve with prior linkages: there is little evidence of any movement to the right of the curve.

[8] Model 3: Joint Wald Chi2 test statistic (and corresponding p-value) of Hypothesis that $\delta 11 = \delta 12$ and $\delta 21 = \delta 22$ is 5.12 (p=0.077). Wald Chi2 test statistic for Hypothesis $\delta 11 = \delta 12$ is 2.64 (p=0.104). Wald Chi2 test statistic for Hypothesis $\delta 21 = \delta 22$ is 0.98 (p=0.323).
Model 4: Joint Wald Chi2 test statistic (and corresponding p-value) of Hypothesis that $\delta 11 = \delta 12$ and $\delta 21 = \delta 22$ is 0.24 (p=0.888). Wald Chi2 test statistic for Hypothesis $\delta 11 = \delta 12$ is 0.01 (p=0.923). Wald Chi2 test statistic for Hypothesis $\delta 21 = \delta 22$ is 0.06 (p=0.803).

We can conclude from evidence in Table 5 and Figures 3 and 4 that there is strong support for H1, and also some support for hypothesis H2. It is confirmed that firms with an ‘optimal’ level of prior boundary-spanning linkages experience higher innovation outputs than those without prior linkages (Hypothesis H2). While we have outlined two potential mechanisms behind this result, evidence of only one of them is found based on Irish manufacturing industry. We find evidence in favour of Hypothesis 3 that firms with prior boundary-spanning linkages experience higher levels of innovation outputs for a given range of current linkages than those without prior linkages. This is the effect due to dynamic economies of scope, as prior openness leads to subsequent increased productivity of a given range of external relationships. However, we do not find any indication that the second potential mechanism behind the positive effect of prior openness – the receding cognitive limit – might be at work. There is no visual indication from our results (Figure 4A) that prior openness allows plants to push back the point at which multiple sources of innovation linkages start to induce decreasing returns with respect to innovation outputs. For such an effect to be evident, the curve with prior openness would have to lie not just above, but also have its turning point[9]) to the right of the curve without prior openness. This is not the case for Figure 4A.[10]

Based on these findings there appears to be a certain optimal level of prior boundary-spanning linkages that is needed today in order to maximise the benefits of open innovation tomorrow, and this lies around three different types of linkage. Having a level of prior linkages below or above that level does not improve the effects of subsequent periods' boundary-spanning linkages on innovation performance.

Does the type of prior linkage matter?

A natural question arising from the analysis about the role of breadth of prior linkages is whether different types of prior linkages matter in improving the impact of openness in subsequent periods. It is clear from the earlier descriptive analysis that supply-chain linkages

[9] I.e. local maxima.

[10] The effects studied here are the average effects over a number of different industries and types of firms. It remains possible that previous experience with linkages has effects on cognitive limits of the management team that materialise in some types of firms, for example in firms where significant amount of absorptive capacity to benefit from external knowledge has been accumulated.

to customers and suppliers are by far the most common forms of link in all waves of the Irish Innovation Panel. We therefore concentrate on the role of these most widespread linkages, and separately consider the possible role of the less common non-supply-chain linkages. The specific reasons why and how linkages from clients, suppliers or outside supply-chain may matter were discussed in Section 2. While supply-chain linkages, at least of an informal nature, may occur almost as a natural part of doing business, investing in non-supply-chain links typically involve a greater degree of strategic intent. Such linkages can be also associated with larger uncertainty, costs and entry barriers than links to firm's customers and suppliers, but potentially (therefore) also with larger benefits.

Table 6 and Figure 5 provide some answers on this issue. The difference between Model 5, 6 and 7 in Table 6 is the way in which the prior openness indicator is calculated. In Model 5 it is equal to 1 for plants that report prior knowledge linkages to their clients in at least one of the two previous waves of the Irish Innovation Panel; in Model 6 it is equal to 1 if the plant reports external linkages to its suppliers, in Model 7 it is equal to 1 if the plant reports linkages outside its supply chain. In all Models in Table 6 we observe again a standard inverse U-shaped relationship between the breadth of linkages (with or without a specific prior openness) and plant's innovation performance, suggesting further support for H1. We also find further evidence in accordance with Hypothesis H2

The joint condition $\delta11 = \delta12$ and $\delta21 = \delta22$ cannot be rejected in the case of prior linkages with suppliers and non-supply-chain partners. Therefore H2 is rejected in these cases: there is no evidence of prior linkages of these types having an impact on the effect of current linkages[11]. However, the effect of boundary spanning linkages on innovation performance is significantly higher for these firms that in previous periods had linkages with their clients[12], This suggests support for H2 – there is some positive effect of prior openness through customer linkages. In addition, where there is some evidence of difference between the 'prior' and no prior' effects, it is clear that this effect arises from an upward shift of the curve:

[11] Model 6: Joint Wald Chi2 test statistic of Hypothesis that $\delta11 = \delta12$ and $\delta21 = \delta22$ is 0.60 (p=0.741). Wald Chi2 test statistic for Hypothesis $\delta11 = \delta12$ is 0.60 (p=0.439). Wald Chi2 test statistic for Hypothesis $\delta21 = \delta22$ is 0.55 (p=0.459).
Model 7: Joint Wald Chi2 test statistic of Hypothesis that $\delta11 = \delta12$ and $\delta21 = \delta22$ is 3.89 (p=0.143). Wald Chi2 test statistic for Hypothesis $\delta11 = \delta12$ in Model 7 is 2.11 (p=0.147). Wald Chi2 test statistic for Hypothesis $\delta21 = \delta22$ is 0.88 (p=0.349).

[12] Model 5: Joint Wald Chi2 test statistic of Hypothesis that $\delta11 = \delta12$ and $\delta21 = \delta22$ is 6.26 (p=0.044). Wald Chi2 test statistic for Hypothesis $\delta11 = \delta12$ is 3.75 (p=0.053). Wald Chi2 test statistic for Hypothesis $\delta21 = \delta22$ is 1.58 (p=0.209).

in the case of previous customer linkages (Model 5): the Wald test also indicates that $\delta 11 > \delta 12$ and $\delta 21 = \delta 22$, as is the case with the 3-plus prior linkages described earlier. These effects are shown graphically in Figures 5A, 5B and 5C. As before, in the case of prior customer linkages there is evidence of an upward shift of the curve where prior linkages exist, but no evidence of a movement to the right of the turning point (Figure 5C)

5. Conclusions and Discussion

This paper explores one aspect of open innovation – how boundary-spanning linkages help shape innovation outcomes. In particular we explore how firms learn from prior openness, thus providing some time dimension to the relationship between openness and innovation.

We find that current 'breadth' of openness in terms of linkages is associated with higher levels of new and improved products as a percentage of sales, but that this relationship has a curvilinear (i.e. inverted U) shape. This effect is consistent and strong across all models, and suggests that the impact of search breadth discovered by Laursen and Salter (2006) extends also to boundary-spanning linkages. We also find evidence that having linkages in previous time periods does have a positive effect on the relationship between current linkage breadth and innovation, suggesting that there are learning effects present in terms of boundary-spanning linkages. However, breadth matters in previous time periods, as it does in the present period. There is a statistically significant difference in the relationship between current openness and performance only for firms which already had at least three different types of linkage in a previous period, but not for those with more than four prior linkages. In addition, the nature of this effect appears to derive largely from economies of scope as firms learn to manage a set of linkages more effectively through time, rather than from pushing back the cognitive limit thereby allowing them to manage more linkages before experiencing diminishing marginal returns to linkage breadth. Prior linkages involving customers seem particularly important in helping boost the effect of current linkages. Notably, however, there is a strong tendency for sub-optimality in terms of linkage breadth: even among firms with prior openness, the mean level of breadth (1.8 linkages) is far below the optimal level as indicated by the implied turning points in the research above.

Overall our results suggest support for the concept of learning effects from previous linkages. Management teams learn from the process of managing multiple relationships in one period, and are able to apply that learning to more efficiently manage a similar set of relationships in subsequent periods. This in turn has implications for the open innovation paradigm and for research on open innovation. Although the open innovation paradigm is, at least implicitly, dealing with openness through time (Chesbrough 2006), most empirical studies rely on cross-sectional data in examining the link between openness and innovation. Our results suggest some support for the open innovation paradigm, inasmuch as prior openness has a positive effect on current openness, but also suggests that future research on open innovation should pay more attention to the time dimension in examining how openness affects innovation[13].

Limitations and future research

It has to be mentioned that the results presented here show associations of prior and current linkages on one hand and current innovation output of the plant on another. Although we have introduced a time dimension into these relationships, we must be careful in interpreting thee associations as strict causal effects. For example, it may be that intensity of innovation activities in the past affects the firm's willingness to invest in knowledge linkages, and to look actively for ways to involve external ideas and knowledge into their innovation process. Also there may be variables that affect directly both innovation performance and firm's breadth of innovation-related linkages. For example, such variable can be the managerial excellence of the managers of the firm or plant, which itself is to an extent an unobserved variable. While we have identified associations that seem to be robust to different specifications and yield several interesting findings outlining the significant role of prior linkages in the effects of current ones, we cannot absolutely discount these effects.

Future research might usefully explore the precise nature of the apparent learning effects identified above. Exactly how do these learning effects occur, and why do they seem to manifest themselves as economies of scope for a given set of linkages rather than pushing back the cognitive limits allowing useful addition of further linkages? And why do links to customers seem to be so important in terms of prior linkage learning effects? It is likely that research to answer these questions will come from more in-depth analysis of individual firms' innovation and linkage activity than from broader survey-based datasets.

[13] "Until greater research is undertaken on the nature of search over time, the full implications of the movement towards 'open innovation' will not be fully understood." (Laursen and Salter, 2006, p 147)

Table 1: Percentage of plants with linkages to different types of partner: all firms (and SMEs)

	Percentage of plants with linkages (percentage of SMEs with linkages)			
	Clients	Suppliers	Competitors	Joint ventures
Period	%	%	%	%
1994-1996	23.0 (21.8)	23.7 (21.9)	5.5 (5.2)	6.6 (6.1)
1997-1999	31.5 (29.4)	32.2 (28.9)	8.8 (8.1)	8.5 (7.7)
2000-2002	21.6 (20.4)	24.8 (23.3)	7.5 (7.0)	5.7 (5.5)
2003-2005	25.8 (24.2)	29.5 (27.6)	6.9 (6.2)	7.6 (7.5)
2006-2008	32.5 (32.0)	32.3 (31.6)	6.3 (6.0)	6.8 (6.8)
	Consultants	Government operated Labs	Universities	Industry Labs
Period	%	%	%	%
1994- 1996	15.8 (14.6)	5.8 (4.8)	10.9 (9.5)	7.3 (6.2)
1997-1999	21.7 (19.5)	10.2 (8.4)	18.2 (15.3)	8.5 (7.2)
2000-2002	15.2 (13.9)	5.4 (4.6)	11.9 (10.1)	5.7 (5.0)
2003-2005	20.7 (19.0)	8.0 (6.4)	18.4 (16.6)	6.8 (4.8)
2006-2008	19.1 (18.4)	6.5 (6.0)	16.4 (15.2)	10.1 (8.8)

Notes: Observations are weighted to give representative results. SMEs defined as plants with less than 250 employees. **Source**: IIP

Table 2: Share (0-1) of plants with different number of external linkages: all firms, 1994-2008

	1994-1996	1997-1999	2000-2002	2003-2005	2006-2008
Share of of plants with linkages	0.39	0.43	0.39	0.39	0.46
... with more than 1 linkage	0.29	0.35	0.28	0.30	0.39
... with more than 2 linkages	0.20	0.23	0.20	0.16	0.27
... with more than 3 linkages	0.12	0.14	0.12	0.09	0.17
... with more than 4 linkages	0.07	0.09	0.06	0.04	0.10

Notes: Observations are weighted to give representative results. **Source**: IIP

Table 3: Breadth of external linkages by period

	1994-1996	1997-1999	2000-2002	2003-2005	2006-2008
A. All plants in IIP					
Mean of Breadth of linkages (no.)	0.96	1.34	0.96	0.91	1.29
SMEs mean of breadth (no.)	0.88	1.19	0.88	0.85	1.24
B. Firms with linkages					
Mean of Breadth of linkages (no.)	2.72	3.09	2.70	2.50	3.14
SMEs mean of breadth (no.)	2.57	2.94	2.60	2.40	3.06

Notes: Observations are weighted to give representative results. SMEs defined as plants with less than 250 employees. **Source**: IIP

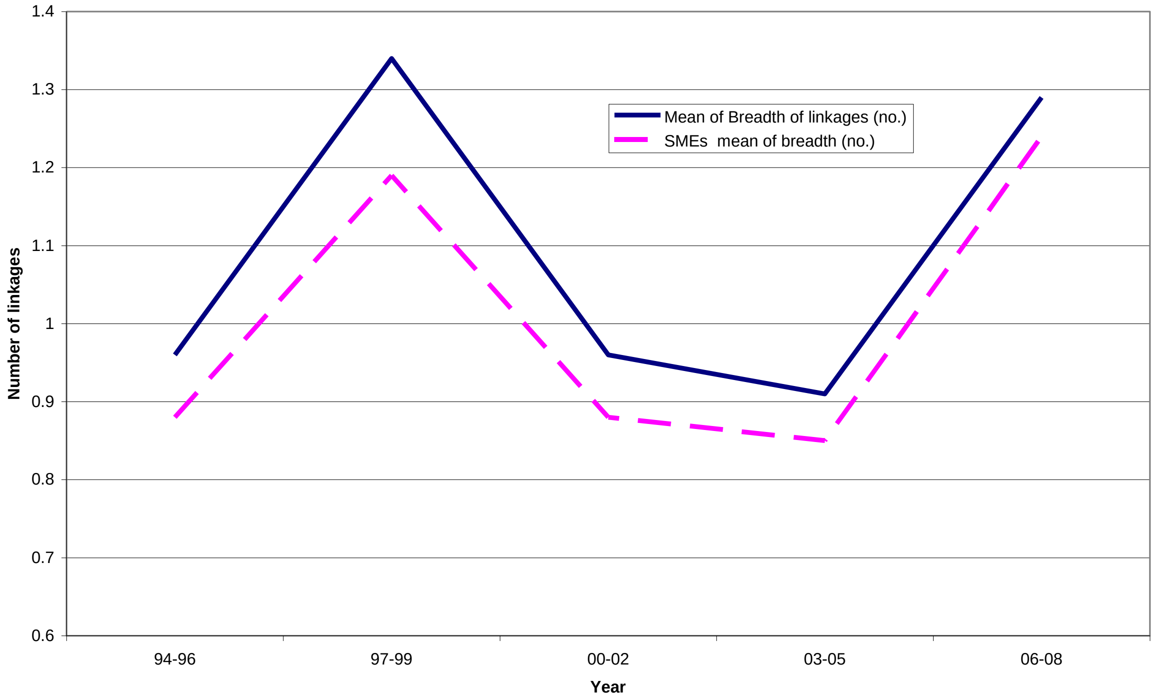
Table 4: Descriptive statistics: respondents with observed prior OI status

	Panel with observed previous OI status N=1919	
	Mean	**Std. Dev**
Innovation measures		
Product innovation dummy	0.6272	0.4837
Proportion of innovative sales (%)	21.8824	28.0372
OI Breadth measures		
Number of linkages	1.0434	1.6590
Number of linkages (for firms that reported external linkages in either of the 2 previous waves of the IIP)	1.798	2.013
Number of linkages (for firms that had no external linkages in either of the 2 previous waves of the IIP)	0.818	1.504
Number of linkages x Prior OI	0.5826	1.3900
Number of linkages x No Prior OI	0.4607	1.1651
Control variables		
Firm undertakes in-house R&D	0.4728	0.4994
Plant size (employment)	76	176
Plant age (years)	32.7326	31.4651
Externally-owned plant	0.2379	0.4259
Percentage of workforce with degree	9.7397	12.7640
Public support for innovation	0.2296	0.4207
Northern Ireland firm	0.3358	0.4724

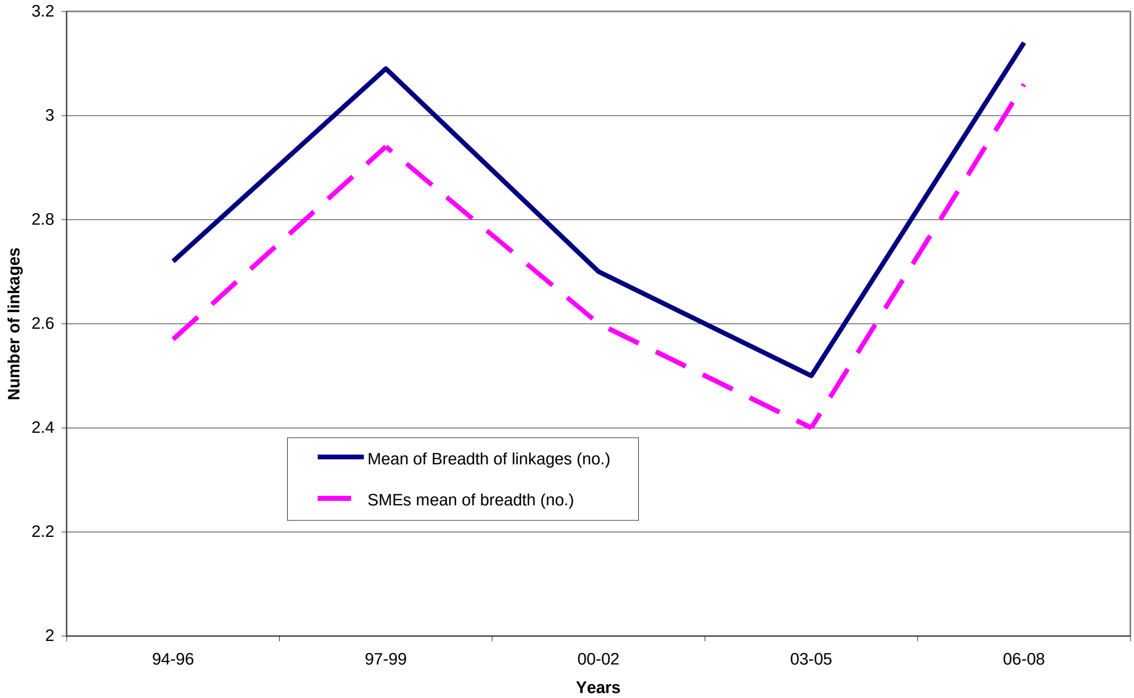
Source: Irish Innovation Panel, waves 2-6 of the survey are included.

Figure 1: Average Breadth of external linkages by time period

A. All plants in IIP

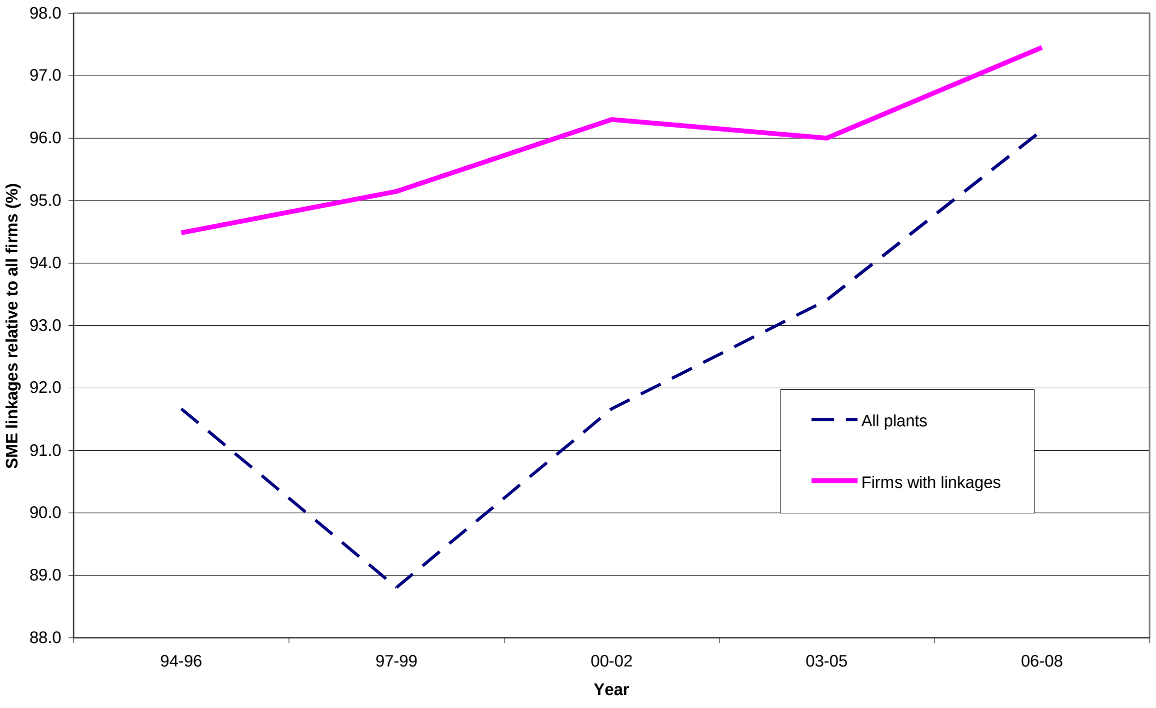


B. Plants with linkages



Notes: Observations are weighted to give representative results. SMEs defined as plants with less than 250 employees. **Source**: IIP

Figure 2: Mean linkages among SME relative to all plants



Notes: Observations are weighted to give representative results. SMEs defined as plants with less than 250 employees. **Source**: IIP

Table 5. Knowledge production function: the role of prior external linkages, by breadth of prior linkages. Method: panel tobit. Dependent variable is share of innovative sales (share of sales of new and improved products).

Prior Linkages:	(1) Model 1 -	(2) Model 2 Prior OI=1 if plant had any prior linkages	(3) Model 3 Prior OI=1 if plant had at least 3 prior linkages	(4) Model 4 Prior OI=1 if plant had at least 4 prior linkages
Number of linkages	7.279***			
	(0.634)			
Number of linkages squared	-0.620***			
	(0.117)			
Number of linkages x Prior OI		7.169***	8.600***	7.233***
		(0.820)	(0.957)	(1.123)
Number of linkages squared x Prior OI		-0.544***	-0.796***	-0.587**
		(0.152)	(0.173)	(0.204)
Number of linkages x No Prior OI		7.635***	6.790***	7.352***
		(0.841)	(0.759)	(0.710)
Number of linkages squared x No Prior OI		-0.780***	-0.574***	-0.647***
		(0.173)	(0.156)	(0.140)
R&D conducted in-house	29.693***	29.736***	29.625***	29.690***
	(0.915)	(0.916)	(0.916)	(0.917)
Employment	0.012**	0.012**	0.012**	0.012**
	(0.004)	(0.004)	(0.004)	(0.004)
Employment squared	-0.015	-0.015	-0.015	-0.015
	(0.009)	(0.009)	(0.009)	(0.009)
Establishment age (years)	-0.093***	-0.092***	-0.091***	-0.093***
	(0.014)	(0.014)	(0.014)	(0.014)
Foreign owned plant	6.311***	6.307***	6.256***	6.307***
	(1.071)	(1.072)	(1.071)	(1.071)
Workforce with degree (%)	0.036	0.033	0.032	0.035
	(0.034)	(0.034)	(0.034)	(0.034)
Govt. support for product innovation	8.687***	8.664***	8.692***	8.684***
	(0.991)	(0.991)	(0.991)	(0.992)
Northern Ireland dummy	-2.276*	-2.261*	-2.250*	-2.270*
	(0.940)	(0.940)	(0.940)	(0.940)
Constant	-9.167***	-8.989***	-9.005***	-9.136***
	(1.348)	(1.360)	(1.349)	(1.349)
Industry control variables	Yes	Yes	Yes	Yes
Time control variables	Yes	Yes	Yes	Yes
Observations	1818	1818	1818	1818
Log likelihood	-3.51e+04	-3.51e+04	-3.51e+04	-3.51e+04

Source: Irish Innovation Panel, waves 2-6 of the survey are included. Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Joint Wald Chi2 test statistic (and corresponding p-value) of Hypothesis that $\delta 11 = \delta 12$ and $\delta 21 = \delta 22$ is 3.56 (p=0.169) in Model 2, 5.12 (p=0.077) in Model 3, 0.24 (p=0.888) in Model 4.

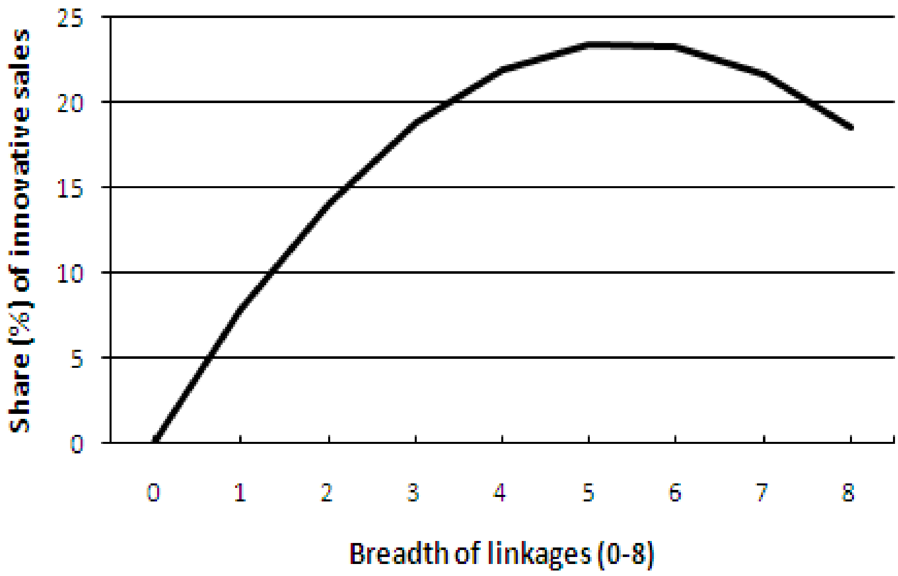
Table 6. Knowledge production function: the role of prior external linkages, by type of prior linkages. Method: panel tobit. Dependent variable is share of innovative sales (share of sales of new and improved products).

Prior Linkages:	(1) Model 2 Prior OI=1 if plant had any prior linkages	(2) Model 5 Prior OI=1 if plant had prior linkages with its clients	(3) Model 6 Prior OI=1 if plant had prior linkages with its suppliers	(4) Model 7 Prior OI=1 if plant had prior linkages outside its supply chain
Number of linkages x Prior OI	7.169***	8.637***	6.776***	8.959***
	(0.820)	(0.896)	(0.913)	(1.247)
Number of linkages squared x Prior OI	-0.544***	-0.809***	-0.526**	-0.833***
	(0.152)	(0.164)	(0.169)	(0.223)
Number of linkages x No Prior OI	7.635***	6.556***	7.613***	7.010***
	(0.841)	(0.781)	(0.768)	(0.696)
Number of linkages squared x No Prior OI	-0.780***	-0.533***	-0.689***	-0.594***
	(0.173)	(0.160)	(0.154)	(0.136)
R&D conducted in-house	29.736***	29.675***	29.720***	29.633***
	(0.916)	(0.915)	(0.916)	(0.915)
Employment	0.012**	0.012**	0.012**	0.012**
	(0.004)	(0.004)	(0.004)	(0.004)
Employment squared	-0.015	-0.015	-0.015	-0.015
	(0.009)	(0.009)	(0.009)	(0.009)
Establishment age (years)	-0.092***	-0.091***	-0.093***	-0.092***
	(0.014)	(0.014)	(0.014)	(0.014)
Foreign owned plant	6.307***	6.199***	6.350***	6.334***
	(1.072)	(1.071)	(1.072)	(1.071)
Workforce with degree (%)	0.033	0.031	0.036	0.031
	(0.034)	(0.034)	(0.034)	(0.034)
Govt. support for product innovation	8.664***	8.693***	8.682***	8.728***
	(0.991)	(0.991)	(0.992)	(0.991)
Northern Ireland dummy	-2.261*	-2.305*	-2.285*	-2.261*
	(0.940)	(0.939)	(0.940)	(0.940)
Constant	-8.989***	-8.909***	-9.192***	-9.199***
	(1.360)	(1.350)	(1.352)	(1.350)
Industry control variables	Yes	Yes	Yes	Yes
Time control variables	Yes	Yes	Yes	Yes
Observations	1818	1818	1818	1818
Log-likelihood	-3.51e+04	-3.51e+04	-3.51e+04	-3.51e+04

Source: Irish Innovation Panel, waves 2-6 of the survey are included. Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Joint Wald Chi2 test statistic (and corresponding p-value) of Hypothesis that δ11= δ12 and δ21= δ22 is 3.56 (p=0.169) in Model 2, 6.26 (p=0.044) in Model 5, 0.60 (p=0.741) in Model 6, 3.89 (p=0.143) in Model 7.

Figure 3: Contribution of linkages to innovative sales, the role of having any prior linkages

A. Linkages and innovative sales (Table 5, Model 1)



B. Linkages and product innovation with and without prior OI (Table 5, Model 2) , Prior OI=1 if plant had any linkages in either of the previous 2 surveys

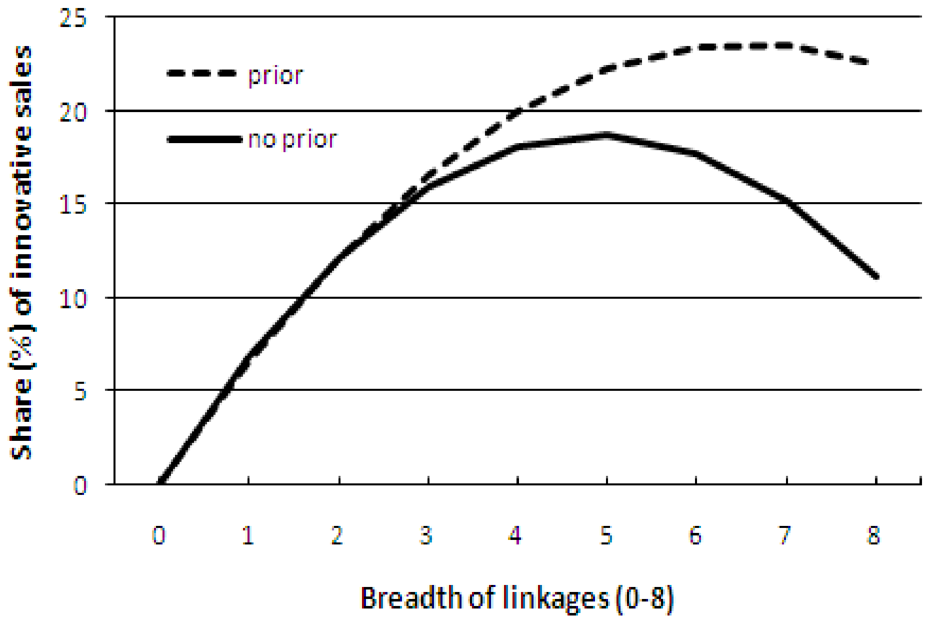
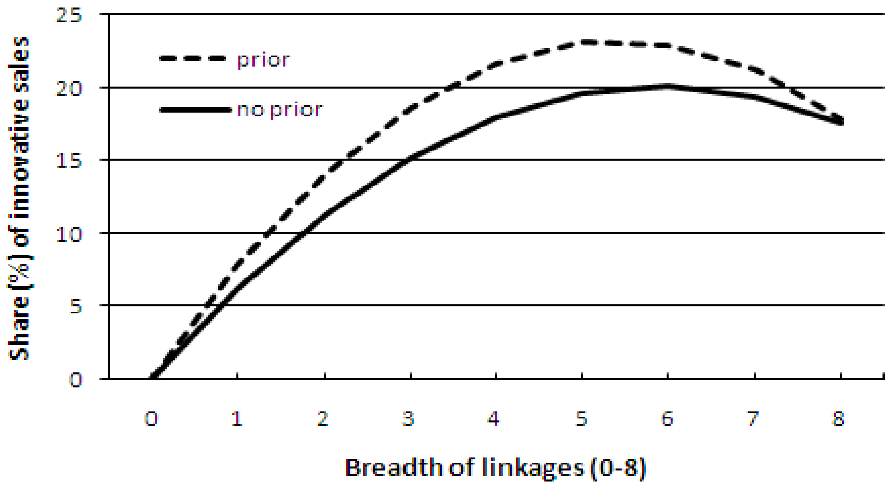


Figure 4: Contribution of linkages to innovative sales, the role of having several prior linkages

A. Linkages and product innovation with and without prior OI (Table 5, Model 3). Prior OI=1 if plant had at least 3 linkages in either of the previous 2 surveys



B. Linkages and product innovation with and without prior OI (Table 5, Model 4). Prior OI=1 if plant had at least 4 linkages in either of the previous 2 surveys

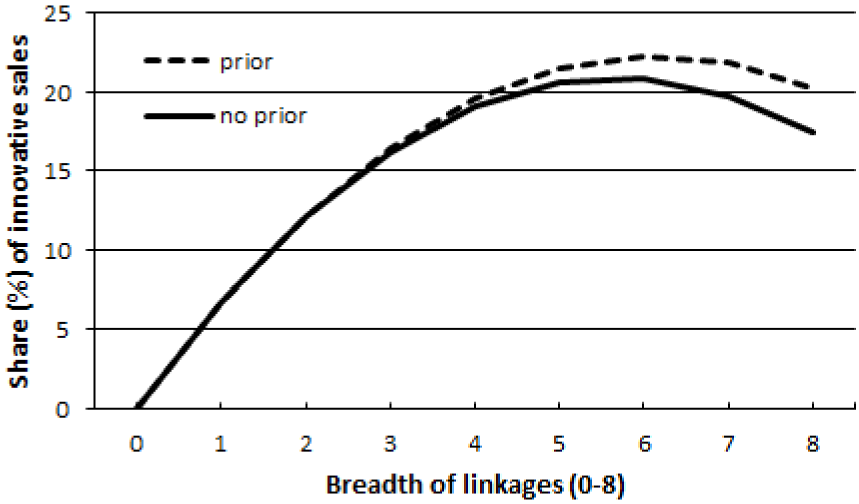
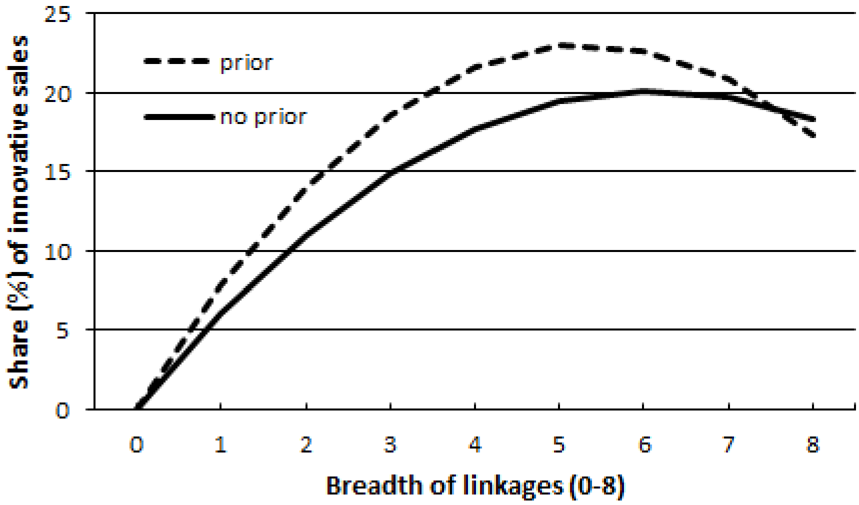
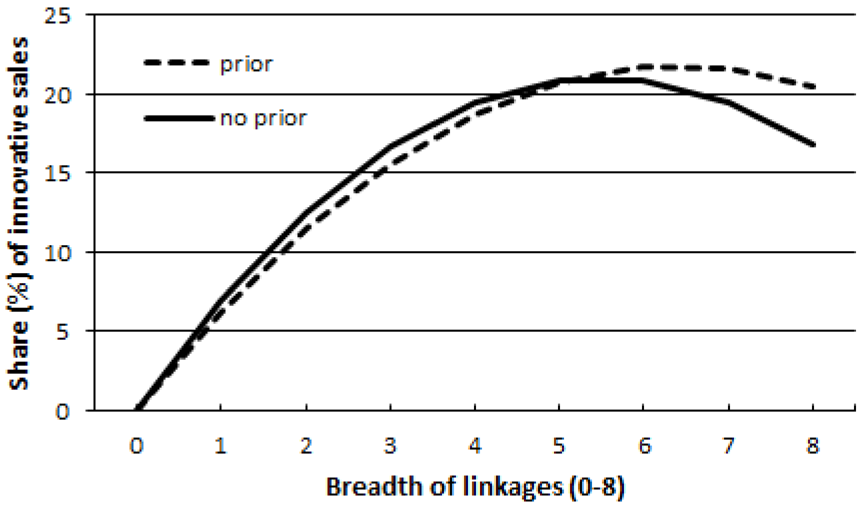


Figure 5: Contribution of linkages to innovative sales, the role of specific linkages

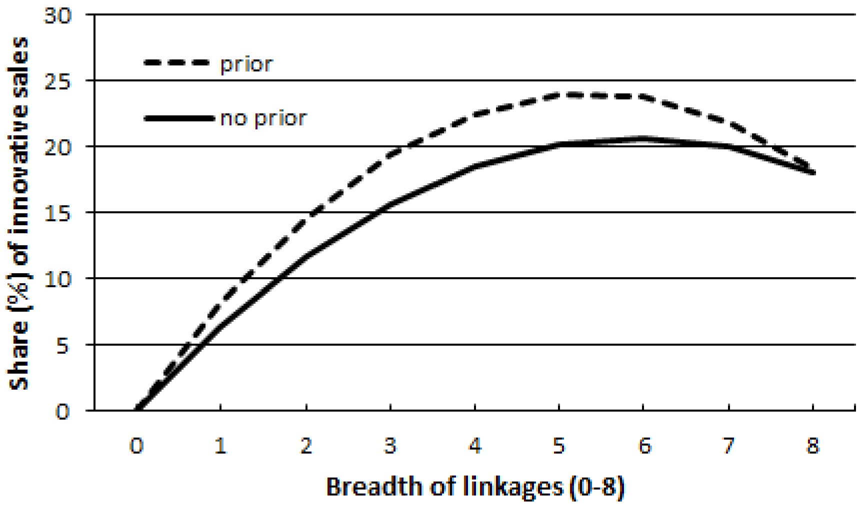
A. Linkages and product innovation with and without prior OI (Table 6, Model 5). Prior OI=1 if plant had linkages with its customers in either of the previous 2 surveys



B. Linkages and product innovation with and without prior OI (Table 6, Model 6). Prior OI=1 if plant had linkages with its suppliers in either of the previous 2 surveys



C. Linkages and product innovation with and without prior OI (Table 6, Model 7). Prior OI=1 if plant had linkages <u>outside its supply chain</u> in either of the previous 2 surveys



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