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Abstract

Traditionally, literature on open innovation has concentrated on analysis of larger firms. We explore whether and how the benefits of openness in innovation are different for small firms (less than 50 employees) compared to medium and large ones. Using panel data over a long time period (1994-2008) from Irish manufacturing plants, we find that small plants have on average significantly lower levels of openness, a pattern which has not changed significantly since the early 1990s. However, the effect of 'breadth' of openness (i.e. variety of innovation linkages) on innovation performance is stronger for small firms than for larger firms. For small firms (with 10-49 employees) external linkages account for around 40 per cent of innovative sales compared to around 25 per cent in larger firms. Small plants also reach the limits to benefitting from openness at lower levels of breadth of openness than larger firms. Our results suggest that small firms can gain significantly from adopting an open innovation strategy, but for such firms appropriate partner choice is a particularly important issue.

Keywords: Open innovation; SMEs; boundary-spanning linkages; learning effects; Ireland

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Contents

1. Introduction

Since the seminal work of Chesborough (2003), the research literature on the benefits and determinants of open innovation has grown rapidly. In a recent review of the open innovation literature, for example, Dahlander and Gann (2010) identify over 150 related papers with an emphasis on case-studies of multinationals such as Procter & Gamble (Dodgson et al.2006), sectoral studies (e.g. Su et al. 2010 on biotechnology), and broadly-based national econometric studies (Laursen and Salter 2006, Leiponen and Helfat 2010, Love et al. 2011). Few of the studies reviewed by Dahlander and Gann (2010) consider specifically the potential benefits of open innovation to small firms or SMEs despite there being plausible reasons to expect the effects and role of open innovation to be different for smaller firms. It has long been acknowledged, for example, that there are marked differences in the scope and focus of the innovation strategies of smaller and larger firms (Acs and Audretsch 1990). Specifically with regard to open innovation, Chesbrough (2010) also suggests that open innovation poses particular challenges for SMEs because of their relative lack of capacity to both seek and absorb external knowledge. Despite these difficulties, recent empirical evidence suggests that some SMEs do purposively engage in open innovation (Brunswicker and Vanhaverbeke 2011), and that the prevalence of open innovation among SMEs has increased in recent years (van der Vrande et al. 2009).

Our contribution here is to explore whether the innovation benefits of openness are different for smaller and larger firms. Specifically, we concentrate on the benefits for firms' innovation performance of openness in knowledge exploration, and consider whether the breadth of firms' innovation linkages have different implications for innovation performance in smaller and larger firms. For example, do larger firms benefit more from more extensive networks of innovation partners due to their greater absorptive capacity? Or, are more extensive innovation networks a greater advantage to smaller firms given their weaker internal resources and therefore greater need to access external knowledge? To measure the

'breadth' of firms' innovation linkages we follow Laursen and Salter (2006) in using a count of firms' different types of innovation partner. Our analysis is based on an unbalanced panel of Irish manufacturing plants that covers five successive three-year surveys, over the period 1994 to 2008. The longitudinal aspect of this data is a significant advantage over other cross-sectional data sources which have been used to investigate the innovation benefits of openness (Laursen and Salter 2006). Panel data models confirm the existence of an inverted U-shaped relationship between the 'breadth' of external innovation linkages and innovation performance for both larger and smaller plants (Laursen and Salter, 2006; Love et al., 2011). Significant differences emerge, however, in the profile of innovation benefits which small and larger plants can derive from any given breadth of external innovation linkages. In particular, as search breath initially increases, each increment to breadth contributes more to innovation performance in smaller plants. At the same time, however, the maximum innovation benefit which small plants can derive from external innovation linkages is smaller for small plants, and occurs at lower breadth than that for larger plants. In other words, small plants experience the limits to openness at lower levels of breadth than larger plants. Our results have implications for innovation strategy in smaller and larger plants and shed new light on the benefits of openness in innovation across the population of innovating firms.

The remainder of the paper is structured as follows. Section 2 reviews recent evidence on the relationship between openness and innovation performance and develops hypotheses related to the nature and breadth of firms' innovation linkages Section 3 describes our data taken from the Irish Innovation Panel and outlines the estimation methods we adopt. Section 4 presents the results of our econometric analysis focussing on the contrasts between smaller and larger firms and Section 5 concludes with a discussion of the strategic and policy implications.

2. Literature Review and Hypotheses

Our key concern here is the relationship between openness and innovation performance. For example, Powell (1998) stresses the potential value of openness in stimulating creativity, reducing risk in the innovation process, accelerating or upgrading the quality of the innovations made, and signalling the quality of firms' innovation activities. External innovation linkages may also increase firms' access to technology developed elsewhere (Mowery, 1990; Niosi, 1999) and their ability to appropriate the returns from innovation (Gemser and Wijnberg, 1995). Moreover, having more extensive networks of linkages or more different types of linkages is likely to increase the probability of obtaining useful knowledge from outside of the firm (Leiponen and Helfat 2010). Empirical evidence also points to the conclusion that knowledge gained from alternative sources tends to be complementary and also complementary with firms' internal knowledge in shaping innovation performance (Roper et al. 2008) [1]. Having more external linkages may therefore both increase the probability of obtaining valuable knowledge and maximise potential knowledge complementarities.

Openness in innovation also has some potential disadvantages. For example, there may be difficulties with managing and protecting intellectual property rights in relationships with partners. Having a larger number or variety of types of innovation partner may also lead to problems with the management and monitoring of these relationships (Simon 1947, Audretsch et al., 1996; Sieg et al. 2007) and the simultaneous absorption of knowledge from a number of different sources. These disadvantages are likely to increase as firms' number of linkages increases with the potential for the firm to reach a 'saturation level' where the innovation benefits of external linkages are maximised. Beyond that level, the addition of another innovation linkage will result in diminishing the innovation performance of

[1] R&D can be seen also as a proxy of absorptive capacity of firms (Cohen and Levinthal 1989). Own R&D may enhance firms ability to benefit from other knowledge sources. For example, in Rosenberg's (1990) view firm's own research capability is seen as indispensable for monitoring and evaluating research that is performed elsewhere.

the firm as the attention of managers is diluted between large numbers of different knowledge sources. Koput (1997) and Laursen and Salter (2006) reflect this in their notion of 'over-searching'.

The balance between the positive effects of firms' external innovation linkages and the potential for over-searching led Laursen and Salter (2006), Leiponen and Helfat (2010) and Love et al. (2011) to expect an inverted U-shaped relationship between the breadth or number of innovation linkages and innovation performance, an expectation confirmed by their empirical analyses. Thus we too expect to find that:

Hypothesis 1: Innovation performance has an inverted U-shaped relationship with a plant's breadth (number) of external innovation linkages.

This does not of course suggest that the shape of the relationship between the breadth of plants' innovation linkages and performance will be the same for small and larger plants. Indeed, there are sound reasons to expect that the relationship may be very different. Small firms may, for example, face particular difficulties in implementing open innovation due to their shortage of the abilities that are needed: i) to build organizational structures and for identification of useful external knowledge; and ii) to absorb externally developed ideas and technologies, even if they were already initially copied or transferred from outside the firm. Also, the low level of knowledge resources at SMEs means that they may be unattractive co-operation partners for others, further reducing the chances of building 'openness' (Chesbrough 2010). This is perhaps reflected in recent empirical evidence which suggests that small producers adopt open innovation practices significantly less than medium sized ones (van de Vrande et al. 2009).

It is tempting to infer from these arguments that smaller firms will benefit less from open innovation. However, the relative benefits of increasing openness for small and large firms may be much more subtle than this and there are good reasons to think that the innovation benefits of openness may actually be stronger for small firms – at least up to some limit. Weaker

internal knowledge resources and ability to invest in in-house knowledge creation potentially make external sourcing of knowledge especially important for small firms. As small firms start, on average, with lower overall levels of knowledge resources, adding more or new types of innovation linkages is likely to have a larger proportionate effect on small firms. For small firms the search for knowledge created elsewhere may also be a more viable way of acquiring new knowledge than in-house generation due to the costs and risks involved in R&D activity. Developing linkages to customers or suppliers, for example, is unlikely to involve the same fixed costs as conducting in-house R&D. SMEs might also benefit more from external linkages because of behavioural advantages related to flexibility and speed of decision making (Vossen, 1998; Acs and Audretsch 1987). Due to this and their ability to specialize to narrow market segments that are unattractive to larger firms, SMEs may be better at quickly adopting the ideas and suggestions by lead users into the product development phase (Chesbrough 2010).

Thus there are reasons why the benefits of each additional linkage may be greater for smaller firms. However, the limits to openness also come into play here. As Hypothesis 1 suggests, the returns to increased openness are likely to become negative at some point as managerial cognitive limits are reached and the diseconomies of 'over-searching' are encountered (Koput 1997; Laursen and Salter 2006). Due to their smaller top management teams and therefore lower capacity to organise and manage larger sets of external linkages, we expect this limit to be reached more quickly among small firms. In other words, while the innovation performance of smaller firms may benefit more from the addition of an additional external linkage, smaller firms will also reach the limits of any additional benefits earlier than larger firms. This leads to two further hypotheses:

Hypothesis 2: The initial marginal benefit to innovation performance of each additional innovation linkage will be greater in small firms.

Hypothesis 3: The maximum benefit to innovation performance of firms' external innovation linkages will be reached at a lower number of innovation linkages by small firms.

3. Data and Methods

Our empirical analysis is based on data from the Irish Innovation Panel (IIP) covering the period 1994 to 2008. The IIP provides information on the innovation activities of manufacturing plants in Ireland and Northern Ireland and comprises five plant-level surveys[2]. These were conducted every three years using similar survey questionnaires with common questions, and capture the same indicators of open innovation during this period. The initial IIP survey used here was conducted between November 1996 and March 1997. It covered plants' innovation indicators for the 1994-96 period, and had a response rate of 32.9 per cent (Roper and Hewitt-Dundas, 1998). The next IIP survey covered the 1997-99 period and reached a response rate of 32.8 per cent. The survey covering the 2000 to 2002 period achieved an overall response rate of 34.1 per cent. Subsequent surveys covering the 2003 to 2005 and 2006 to 2008 periods achieved response rates of 28.7 per cent and 38 per cent respectively. We note that the resulting panel is unbalanced, both due to the foundation and closure of plants and survey non-response.

Our focus here is on firms' responses to a question asked in each of the different waves of the IIP: *Over the last three years did you have links with other companies or organisations as part of your product or process development?* Plants that confirmed having linkages were then asked to indicate which types of external partners they had during the 3-year period covered by the survey. Eight partner types of external linkages were outlined in the survey questionnaire: linkages to customers, suppliers, competitors, joint ventures, consultants, universities, industry operated laboratories, and government operated laboratories. Figure 1 shows how

[2] The IIP dataset is at plant level. However, most of the observations are single plant firms. Overall, 58 per cent of all observations in the IIP are from single plant firms: among small plants this figure is significantly higher at 77 per cent.

the average number or breadth of linkages has changed through time for small plants (with 10-49 employees) and larger plants. On average, over the whole sample period, small plants have an average of 0.82 external linkages, half that of larger plants (1.64, Table 1)[3]. There is little evidence in our Irish dataset supporting the idea of a 'paradigm shift' towards open innovation among small or larger plants such as that found in the Netherlands by van de Vrande et al. (2009) (Figure 1).

Not surprisingly perhaps, the most common external partners in plants' innovation activity were customers and suppliers (Table 2). Links to universities, labs, competitors and other partners are much less common. This regularity holds for both small and larger plants. Small plants in particular, have significantly fewer supply chain linkages to customers and suppliers than larger plants. For example in the 2006 to 2008 period, 33 per cent of small plants and 53 per cent of larger plants had supply chain linkages. Notably, the gap between small and large plants is even larger in terms of links to universities and laboratories and linkages to competitors and others knowledge sources (Table 2).

Our econometric analysis is based on estimation of the innovation production function with innovation linkages included among the explanatory variables (Crépon et al. 1998; Laursen and Salter, 2006; Love et al., 2011). The innovation production function is estimated separately for small and medium/large plants. Our econometric model is similar to the one used in Laursen and Salter (2006) based on UK data and Love et al. (2011) based on the full sample of the IIP dataset. As the dependent variable in the innovation production function we use a common innovation output indicator – the proportion of plants' sales (at the end of each three-year reference period) derived from products that were either newly introduced or improved during the previous three years. This variable reflects plant's ability to introduce new or improved products to the market and their subsequent commercial success. On average, 20 per cent of the

[3] The difference between the mean values of linkages for small and larger firms is highly significant (t=13.89).

sales of small plants were from newly introduced or improved products compared to 29 per cent for larger firms (Table 1).

We estimate the innovation production function separately for small and larger plants. Let $INNOV_{it}$ be an innovation output indicator (for plant *i* at survey period *t*), and FCB_{it} a vector of plant level control variables and OI_{it} represent plants' breadth or number of innovation linkages. The innovation production function with sector specific (λ_j) and time effects (τ_t) can then be written:

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

Here, *i* denotes the plant, *t* period (IIP wave), and *j* sector, ϖ_{it} is an idiosyncratic error term. Hypothesis 1 implies that $\delta_1>0$ and $\delta_2<0$, for both sets of plants. Hypothesis 2 implies that the innovation benefits of external linkages will be greater for small firms. We can test this hypothesis based on a comparison of δ_1 and δ_2 in the innovation production functions for smaller and larger firms. It also proves helpful to plot these relationships highlighting contrasts in the shape and turning point of the relationship between the number of linkages and innovation performance as anticipated in Hypothesis 3.

Our choice of estimation approach for Equation (1) reflects the form of our dependent variable; the share of new or improved products in sales can take values between 0 and 100. Therefore we use a panel tobit model and in each equation a set of sector indicators at the 2- digit level and a series of time dummies. We also include in each model a set of controls for other plant characteristics which have been found in many previous studies to affect innovation outputs. One of the most important innovation inputs is an indicator whether or not plants are under-taking in-house R&D (Crépon et al. 1998, Griliches 1995; Oerlemans et al. 1998). This is also an indicator of absorptive capacity (Cohen and Levinthal 1990). In our sample, in-house R&D was performed by 29 per cent of small plants and 60 per cent of larger plants (Table 1). We also include variables intended to reflect the

strength of plants' internal knowledge base – multinationality and the age and scale of the plant (Klette and Johansen, 1998). A multinationality dummy is incorprated as a control variable because links between plants within a multinational are a potentially important channel for international knowledge transfer (Dunning 1988, Lipsey 2002). On one hand, multinational firms may be more able to reap the benefits of open innovation than domestic firms due to access to knowledge resources within the firm. Multinationality may also reflect the higher absorptive capacity of the plant. Additionally, we include the share of each plant's employees which have a degree level qualification, an indicator of labour quality (Freel 2005) and potentially also absorptive capacity. Models also include a dummy variable to indicate whether or not plants had received public support for their innovation activity (Hewitt-Dundas and Roper 2009). The Herfindahl index is also included as a broad proxy for sectoral competition (at the 2-digit level).

Finally, before turning to our empirical results it is important to acknowledge the potential for survey-based studies such as ours to suffer from common method variance or bias (CMB). CMB is the variance due to the general measurement methods rather than due to the measured key explanatory variables themselves (Podsakoff et al. 2003, Sharma et al. 2010, etc) and may lead to biased estimates of the effects of key variables of interest in survey-based studies (Sharma et al. 2010). Three aspects of our analysis reduce the potential for CMB: first, our analysis is based on a series of surveys rather than a single survey; second, we estimate a relatively complicated innovation production function with the dependent variable measured at the end of the period and key explanatory variables reflecting plants' innovation activities during the previous three years; third, the answer scales of our dependent variable and key explanatory variables are very different. Formally, we have checked for CMB using the Harmon's one factor test (Podsakoff and Organ 1986) and the marker variable technique (e.g. Malhotra et al. 2006, Lindell and Whitney 2001). Harmon's one factor test is regularly used in the literature, for example, in a related study to ours by Leiponen and Helfat (2010). Harmon's one-factor test

consists of running a factor analysis of all key variables in the model. If the first unrotated factor accounts for a relatively small share of the total variance (not more than 50 per cent), the implication is usually that CMB is not likely to be a significant problem. Harmon's one factor test suggests in our data this single factor explains only about 27 per cent of the total variation of the main variables in our model.

Some authors have argued, however, that this test may be insufficient to test for the presence of CMB (Podsakoff et al. 2003). Therefore we have also implemented the marker variable technique (Lindell and Whithey 2001, Sharma et al. 2010). This approach is based on comparison of pairwise correlations in the case of key variables in the dataset. In this technique, a 'marker variable' is sometimes identified as a variable that is theoretically unrelated to at least one variable in the study. Alternatively, where such a marker variable cannot be identified a priori, the variable with the lowest correlation with other variables is chosen as the 'marker' (Sharma et al. 2010). In this last case, the smallest positive correlation in the correlation matrix of variables used in the study is considered as a proxy for CMB. Based on both alternatives of the marker variable technique, there appears to be no reason to suspect significant CMB in our analysis.[4]

4. Results

The results of estimating equation (1) are shown in Table 3. There is supporting evidence for Hypothesis 1, i.e. there is strong evidence of an inverted U-shaped relationship between openness and innovation outputs for both small and larger firms (Laursen and Salter, 2006; Leiponen and

[4] One marker variable we tried was the indicator of government support to exports. The lowest correlation of this variable with the ones in Model 1 or 2 was with age of the plant (0.0049). (There were several other variables with similar low correlation with government support to exports.) Taking this correlation as a measure of the CMB and subtracting it from the other pairwise correlations (as outlined in more detail in Sharma et al. 2010) does not significantly affect the correlations between the variables used in our regression analysis, in Equation 1 or 2. Also, other marker variables that we tried yield similar result. Thus, CMB is not an important problem here.

Helfat, 2010; Love et al. 2011). In Figure 2 the coefficients on the number of linkages and its square in Table 3 (Models 1 and 2) are used to plot the relationship between breadth of openness and innovation performance. It is evident that among small plants the innovation benefits of openness is greater than that for larger plants reflecting the larger coefficient on breadth in the estimated model for small plants. However, as almost all small plants have fewer than six types of external linkage the effect of breadth of open innovation on innovation performance is, in effect, stronger for almost all small plants. This provides very strong support for Hypothesis 2.

Hypotheses 3 posited that the maximum innovation benefits of openness would be reached earlier in the case of small plants. This is indeed the case, as shown in Figure 2. The turning point of the openness-innovation performance relationship for small plants occurs at about four types of external linkage: adding additional linkages beyond this point is associated with lower innovation output. By contrast for larger firms increasing breadth of linkages continues to be associated with greater innovation output, albeit at a decreasing rate. This tends to support the view that governing many different types of linkages requires significant co-ordination capacity, precisely the kind of resources and co-ordination abilities which may be lacking in smaller firms.

One issue with Figure 2 is that it does not account for the different starting point in terms of level of innovation performance of small and larger plants which may reflect, for example, their different levels of internal knowledge resources. This is taken into account in Figure 3 where we combine equation coefficients (from Table 3) with average values of each explanatory variable other than breadth to define average predicted levels of innovation performance. Here the underlying relationships between breadth of linkages and innovation output remains unchanged, but we show the level of share of new or modified products in sales that is attained for an average firm in both groups (i.e. the level of innovation output attained given all the other regression coefficients and average values of explanatory variables). The results of our regression analysis, combined

with information about mean values of the control variables in each group, show that the level of innovation output of the average small plant is lower than the level of the average large plants as long as the number of different types of innovation linkages is less than 3 or above 4. If small plants have 3 or 4 different types of linkages they attain, on average, the same level of innovation output as larger plants. This reinforces the message of Hypothesis 2 that – within limits – small firms can make up for a lack of other internal innovation resources by developing external linkages with innovation partners.

Finally, as a robustness check, we use the McDonald and Moffitt (1980) decomposition to divide the effects of breadth of linkages in Column (1) and (2) of Table 3 into two components. First, the marginal effect on the probability of having positive innovation output (i.e. propensity to innovate). Second, the marginal effect on the expected value of innovation output conditional on the plant engaging in innovation. The results confirm that the marginal effects of the breadth of innovation linkages both on the probability that a plant will engage in innovation and on innovation intensity among innovators is higher among small plants (Table 4). This suggests that the benefit of adding an additional external linkage is greater for small firms both in terms of its effect on their propensity to innovate *and* in terms of increasing their level of innovation outputs once over the innovator hurdle. The effect on the uncensored part of the distribution of innovation performance (i.e. the 'intensity' effect) accounts for 32 per cent of the total effect on innovation performance of small plants. The corresponding figure for large and medium sized plants amounted to 42 per cent. This shows clearly that the effect on the propensity to innovate is proportionally more important for small plants.

The control variables used in the tobit models largely take the expected signs but also suggest some significant differences between the determinants of innovation performance in small and larger plants. For example, R&D is an important input in the innovation production function for both small and larger plants but has a significantly greater effect on

innovation performance in smaller firms[5]. Similarly, exposure to export markets (χ^2=3.06, ρ=0.002) and having a more highly qualified workforce (χ^2=2.43, ρ=0.015) both have a proportionately greater effect on innovation performance in smaller rather than larger plants (Love et al; 2010; Freel, 2005). Other factors such as external ownership (χ^2=0.02, ρ=0.987) and receiving public support (χ^2=0.95, ρ=0.340) for innovation also have positive effects on innovation performance, effects which are similar in scale for small and larger plants (Hewitt-Dundas and Roper, 2009). Interestingly, sectoral concentration as measured by the Herfindahl index is only significant for larger firms where, somewhat contrary to expectations, it has a positive rather than negative sign. This suggests that for larger firms, at least, higher levels of sectoral competition necessitate, or perhaps encourage, higher levels of innovative activity as Baumol (2002) suggests.

5. Conclusions

This paper investigates how the role of openness in the innovation process differs between small and larger plants. Specifically, we examine the role of breadth of external linkages and its link to innovation performance. There are plausible reasons to expect that small firms will be less open, and also to expect that they will benefit more from each additional linkage but also reach the limits of that beneficial effect at a lower level of 'openness' than larger firms. However, there is very little direct evidence on whether and how this differential effect operates in practice.

Based on an econometric analysis of Irish plant-level panel data from 1994 to 2008 our results - which generally accord with *a priori* reasoning - suggest that open innovation works very differently in small firms. First, small firms are consistently less open in terms of their number of external linkages than larger firms and this is consistent over the 1994 to 2008 period. Second, as expected, we find an inverted U-shaped relationship between the extent ('breadth') of openness and firms' innovation

[5] Comparing Models 1 and 2 in Table 3, for example, a test of the equality of the coefficients on in-house R&D in the two models suggests a χ^2=5.80, ρ< 0.000.

performance, both for small and larger firms (Figure 2). Third, small firms gain more from each additional linkage type than do larger firms. Fourth, small firms reach their limit to benefitting from openness earlier than larger firms. Taking the last two findings together suggest that larger firms are able to continue benefitting from increased linkage breadth (albeit at a decreasing rate) beyond the limit at which increased breadth has started to have negative effects for small firms (Figures 2 and 3).

Perhaps the most important conclusion from these findings is that openness is proportionately more important to innovation in smaller plants. On average, small firms have 0.8 external innovation linkages (Table 1) which contribute around 8 percentage points to innovative sales (Figure 2). This accounts for around 40 per cent of the average level of innovative sales of smaller firms (20.4 per cent, Table 1). For larger firms, which have an average of around 1.6 external innovation linkages (Table 1), those linkages account for around 7 percentage points or around a quarter of average innovative sales by larger plants. So, where they are able to take advantage of external linkages, small firms often have more to gain than their larger counterparts. Our findings therefore underline the importance of paying attention to the heterogeneity of effects of open innovation across different types of plants. Average effects based on all plants in manufacturing industry clearly hide large variations across different groups of plants.

While it is tempting to draw immediate conclusions on innovation strategy for small firms or indeed SME policy from these results, caution must be exercised in suggesting the benefits of external linkages for smaller firms. Our findings certainly suggest that small firms may well have a bigger incentive than hitherto imagined to develop innovation linkages with external partners. However, partnering involves two parties: as Chesbrough (2010) points out, small firms may often be unattractive (or unnoticed) co-operation partners for other enterprises, especially large ones. This may mean that the costs involved in seeking and finding a suitable partner may well be beyond the means of many small firms. We

also know little about the costs involved in developing such relationships, an area which provides a potentially valuable focus for future research. In addition, it should be borne in mind that developing such linkages is very much a minority sport among small firms: the average number of linkages for small firms in our sample is less than one, with only 21 per cent of small firms having three or more types of linkage. Nevertheless, the potential benefits of increased breadth are great: as indicated in Figure 3, for our sample an average small firm with no innovation linkages has a level of innovation intensity approximately 12 percentage points below that of an average firm with more than 50 employees. By the time both firms have reached three types of external linkage, this gap has completely closed, suggesting that external boundary-spanning linkages can be an effective strategy for small firms to boost markedly their level of innovativeness.

In strategic terms our results suggests the value of open innovation strategies for small firms involving, perhaps, up to four types of external partner. The limited resources available within small firms for managing and developing these external relationships, however, suggests the importance of the careful selection of the most appropriate or beneficial innovation partners. Criteria for partner selection will of course vary, reflecting the internal capabilities of each small firm and their innovation ambitions (Jeon et al., 2011). In policy terms, however, this suggests the potential importance of partnership brokering intermediaries which might encourage small firms to adopt more open innovation strategies and help to identify potential innovation partners (Cantner et al., 2011). Recent examples of such initiatives would be the innovation voucher schemes developed in a range of European and other OECD countries (Bakhshi et al., 2011). A key design feature of such schemes has been efficient brokerage or processes to match SMEs with appropriate knowledge or service providers. The extent of such activity has varied widely, however, depending on the specific target group of SMEs. In the early Dutch innovation voucher schemes the administering agency's brokering activity was limited to the compilation of a list of eligible partners with SMEs then required to select their own partner. Similar approaches have been

adopted in the Irish innovation voucher scheme and the UK Creative Credits programme. An alternative approach involving more active brokering activity has been adopted in some regional UK programmes with SMEs actively supported in identifying potential innovation partners (Bakhshi et al., 2011). Perhaps the key point here is that where SMEs are inexperienced in working with external innovation partners they are likely to need more support in selecting partners and then developing their external relationships.

Our results provide support for the value of such initiatives in terms of the innovation benefits they can generate. Two limitations of our analysis suggest the need for some caution in drawing more specific policy implications. First, while our analysis does provide an indication of the benefits of openness for small and larger firms, a more complete picture would also require an assessment of the costs of developing new linkages and how these costs differ between smaller and larger firms. For example, while the resource cost of developing a new linkage may be similar in smaller and larger firms, the opportunity cost may be markedly greater in small firms. This may offset some or all of the higher level of innovation benefits in smaller firms. As far as we are aware there is no specific evidence comparing the relative costs and benefits of innovation linkages in larger and smaller firms but for a group of Belgian firms Faems et al. (2010) do demonstrate that the costs of developing technology alliances can actually outweigh their (indirect) benefits on firm performance. Investigating more specifically the costs and benefits of openness for small and larger firms is a potentially interesting and useful theme for future research. A second limitation of our analysis, which restricts its direct policy application, is the broad nature of our measure of the breadth of plants' portfolio of innovation linkages. This implicitly makes a number of assumptions: that each type of linkage is of equal innovation value, that this value remains the same through time, and that the relative innovation value of each type of linkage is the same for larger and smaller firms. Each of these assumptions suggests the value of further research to develop more realistic weighting structures for different types of linkages which can

provide a better indication of the innovation value of openness and therefore the value of alternative types of policy interventions.

Table 1: Descriptive statistics of variables used in regression analysis

Variable	Small plants Mean	Small plants Std. Dev.	Medium and large plants Mean	Medium and large plants Std. Dev.
Sales from new or improved products (%)	20.43	28.49	29.39	30.78
R&D conducted in-house (dummy)	0.39	0.49	0.60	0.49
Number of linkages (0…8)	0.82	1.46	1.64	2.03
Linkages within supply chain (dummy)	0.28	0.45	0.46	0.50
Linkages with universities and labs (dummy)	0.13	0.33	0.30	0.46
Other linkages (dummy)	0.19	0.39	0.33	0.47
Employment (no.)	23.96	11.33	199.53	389.19
Age of the plant (years)	28.57	27.66	32.22	32.92
Foreign owned plant (dummy)	0.14	0.35	0.49	0.50
Export dummy	0.42	0.49	0.72	0.45
Workforce with degree (%)	9.63	14.15	10.57	12.54
Govt. support for product innov. (dummy)	0.18	0.39	0.30	0.46
Herfindahl index	0.26	0.13	0.28	0.11
Number of observations	2170		1672	

Source: IIP. Note: Dummy variable 'Other linkages' includes linkages to competitors, joint ventures and consultants.

Table 2: Percentage of plants with linkages to different types of partner

	Percentage of plants with linkages:		
Small plants:			
Period	Within supply chain %	To universities and labs %	Other linkages* %
1994-1996	24.9	9.8	16.9
1997-1999	31.9	16.8	24.1
2000-2002	24.7	10.4	15.5
2003-2005	23.7	11.2	17.1
2006-2008	33.2	12.2	18.3
Medium and large plants:			
Period	Within supply chain %	To universities and labs %	Other linkages* %
1994- 1996	43.2	26.5	30.8
1997-1999	51.2	30.7	34.9
2000-2002	41.1	26.5	32.1
2003-2005	43.8	29.2	26.6
2006-2008	53.1	43.3	38.8

Notes: Observations are weighted to give representative results.

Source: IIP. *- linkages to competitors, joint ventures and consultants.

Table 3: Knowledge production function: the role of breadth and type of external innovation linkages

	Breadth of linkages	
	(1)	(2)
Dep. var.: Sales from new or improved products (%)	Model 1, Small plants	Model 1, Medium and large plants
R&D conducted in-house	32.843***	21.513***
	(1.009)	(1.134)
Number of linkages	11.808***	4.488***
	(0.733)	(0.655)
Number of linkages squared	-1.309***	-0.232**
	(0.148)	(0.108)
Supply chain linkages (dummy)		
University/lab linkages (dummy)		
Other linkages (dummy)		
Employment (no.)	0.406**	0.010***
	(0.182)	(0.003)
Employment (no.) squared	-0.009***	-0.000*
	(0.003)	(0.000)
Plant age (years)	-0.102***	-0.115***
	(0.018)	(0.017)
Foreign owned plant	5.892***	5.259***
	(1.324)	(1.127)
Export dummy	6.732***	1.929
	(0.991)	(1.267)
Workforce with degree (%)	0.284***	0.138***
	(0.036)	(0.044)
Govt. support for product innov.	7.717***	5.142***
	(1.178)	(1.131)
Herfindahl index	8.861	20.734**
	(6.504)	(8.401)
Constant	-22.794***	-11.360***
	(3.400)	(3.297)
Industry dummies	Yes	Yes
Period dummies	Yes	Yes
Observations	1674	1348
Log-likelihood	-3.57e+04	-2.46e+04

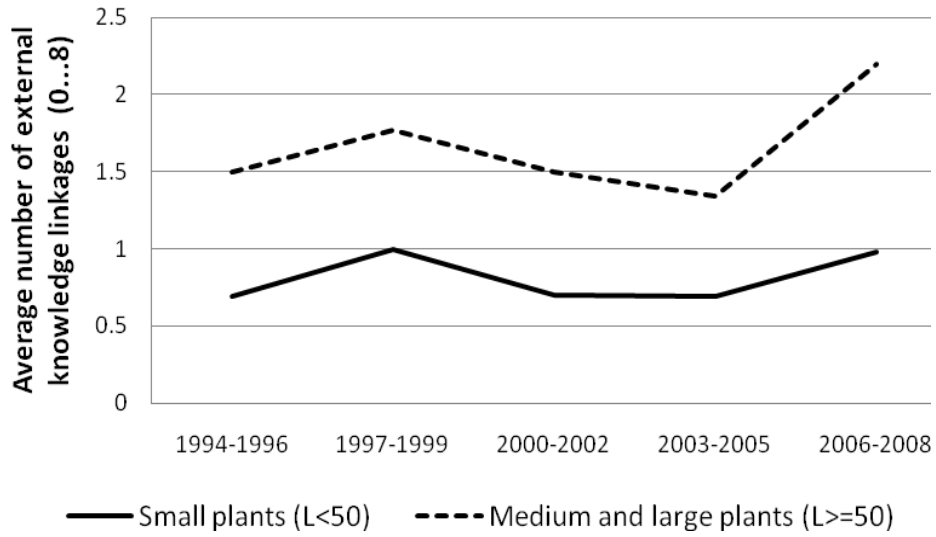
Source: Irish Innovation Panel, waves 2-6 of the survey are included. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Random effects tobit models. Dummy variable 'Other linkages' includes linkages to competitors, joint ventures and consultants. Observations are weighted in regression analysis to give representative results.

Table 4: McDonald and Moffitt (1980) decomposition of the effects of breadth of linkages in tobit model in Table 3

	Marginal effects at sample means on innovation performance	
	Marginal effects on the expected value of innovation performance conditional on having innovation output	Marginal effects on the probability of having innovation output
	Small plants:	
Number of linkages	3.564***	0.082***
Number of linkages squared	-0.403***	-0.009***
	Medium and Large plants:	
Number of linkages	1.806***	0.029***
Number of linkages squared	-0.086**	-0.001**

Source: Irish Innovation Panel, waves 2-6 of the survey are included. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Marginal effects are calculated based on model in Equation 1, as estimated with tobit model in Columns 1 and 2 of Table 3.

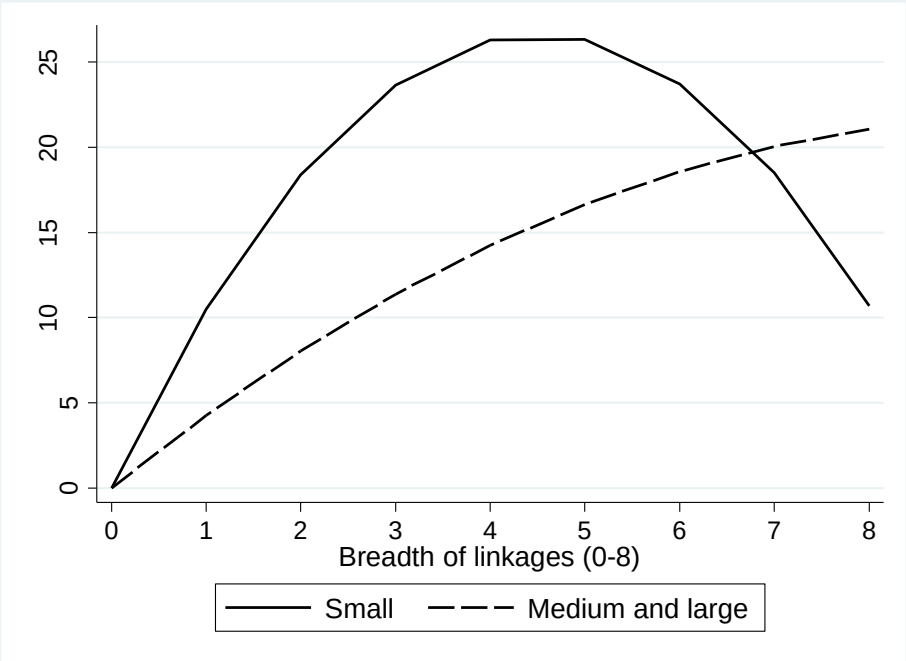
Figure 1: Average number of knowledge linkages



Notes: Observations are weighted to give representative results. Small plants are defined as plants with less than 50 employees.

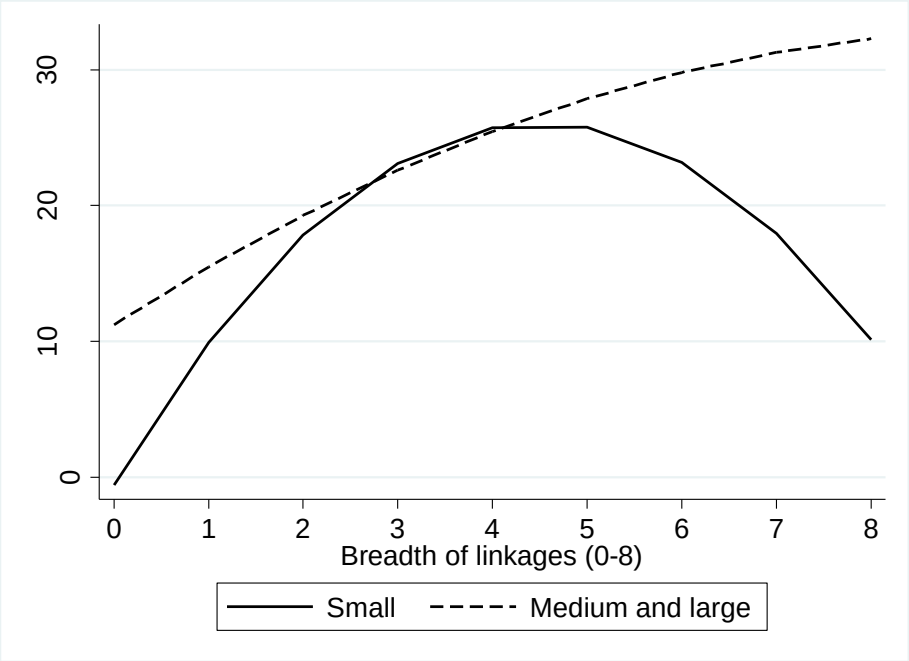
Source: IIP

Figure 2: Relationship between breadth of openness and innovation performance



Source: regression results in Column 1 of Table 3.

Figure 3: Level of innovation performance reached on average for different levels of breadth of openness: accounting for different initial levels of innovation output.



Source: regression results in Column 1 of Table 3. (Starting point for small plants: -0.56, for larger plants 11.22)

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