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Externalities of openness in innovation☆

Stephen Roper[a,*], Priit Vahter[b], James H. Love[c]

[a] Enterprise Research Centre and Warwick Business School, University of Warwick, Coventry CV4 7AL, UK
[b] Faculty of Economics and Business Administration, University of Tartu, Tartu 51009, Estonia
[c] Enterprise Research Centre and Economics and Strategy Group, Aston Business School, Aston University, Birmingham B4 7ET, UK

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ABSTRACT

Discussion of open innovation has typically stressed the benefits to the individual enterprise from boundary-spanning linkages and improved internal knowledge sharing. In this paper we explore the potential for wider benefits from openness in innovation and argue that openness may itself generate positive externalities by enabling improved knowledge diffusion. The potential for these (positive) externalities suggests a divergence between the private and social returns to openness and the potential for a sub-optimal level of openness where this is determined purely by firms' private returns. Our analysis is based on Irish plant-level panel data from manufacturing industry over the period 1994–2008. Based on instrumental variables regression models our results suggest that externalities of openness in innovation are significant and that they are positively associated with firms' innovation performance. We find that these externality effects are unlikely to work through their effect on the spread of open innovation practices. Instead, they appear to positively influence innovation outputs by either increasing knowledge diffusion or strengthening competition. Our evidence on the significance of externalities from openness in innovation provides a rationale for public policy aimed at promoting open innovation practices among firms.

1. Introduction

In this paper we identify a new externality which occurs as part of firms' innovation activity and provide some preliminary evidence of its empirical significance. Our starting point is the idea of open innovation in which firms combine externally available knowledge with internal knowledge inputs to generate new innovations. Seen as an alternative to the 'closed', largely internal, innovation models of the past, this has led to claims of a 'paradigm shift' in the organisation of firms' innovation activity (Chesbrough, 2003a,b), and suggestions that by adopting an open innovation approach firms can improve their innovation performance (DIUS, 2008). To date, however, the implications of any shift in innovation practice towards open innovation have largely been considered at the level of the individual firm (Chesbrough, 2006; Dodgson et al., 2006; Laursen and Salter, 2006; Lichtenthaler and Ernst, 2009) leading to calls for further research to validate the private benefits of open innovation to firms in different operating contexts (Chesbrough, 2006).

These firm-level, strategic analyses may, however, be excluding potentially important and dynamic social benefits. For example, the increased adoption of open innovation may lead to greater innovation spillovers – resulting from new innovations – or spillovers mediated through firms' new open innovation linkages (Czarnitzki and Kraft, 2011; Vahter, 2011). Here, however, we focus on a rather different issue arguing that the more widespread is the adoption of openness in innovation the greater will be the potential for knowledge diffusion through unplanned and/or informal, unpriced mechanisms. If significant, these 'externalities of openness' – which result from firms' openness rather than their R&D inputs or innovation outputs – suggest that the social benefits of widespread adoption of openness in innovation may be considerably greater than the sum of the achieved private benefits. Adoption decisions by individual firms based purely on the private benefits of 'openness' would then lead to an average level of openness which is below the socially optimal level. Positive evidence of the existence of externalities of openness in innovation would therefore provide a justification for public intervention to encourage more 'open' innovation strategies and so maximise the potential social benefits of openness.[1]

* Corresponding author. Tel.: +44 2476522501.
E-mail addresses: stephen.roper@wbs.ac.uk (S. Roper), priit.vahter@ut.ee (P. Vahter), j.h.love@aston.ac.uk (J.H. Love).

[1] This argument is essentially similar to that often applied to the distinction between the private and social benefits of R&D, and the resulting justification for public intervention to support private R&D investments (Arrow, 1962).

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Our focus in this paper is on developing an initial conceptual framework for the mechanisms through which externalities of openness may occur and to provide some empirical evidence of their significance. We identify three separate mechanisms through which externalities of openness may operate related to ambient knowledge or buzz, demonstration or imitation effects and through competition. Empirically, we endeavour to find out whether firms located in sectors which are more 'open' – i.e. have a higher incidence of open innovation – do have higher innovation productivity. Our analysis goes beyond the estimation of simple correlations by using an instrumental variables approach to identify the innovation effects of externalities of openness and how these externalities are working. We estimate these effects using panel data on Irish manufacturing firms taken from the Irish Innovation Panel (IIP) and covering the period 1994–2008. Our empirical approach is based on the knowledge production function (Crépon et al., 1998; Griffith et al., 2006), with innovation performance as one key dependent variable. We find evidence supporting the existence of positive externalities of openness in increasing innovation productivity. Our evidence also suggests these effects on innovation productivity work through improved knowledge diffusion or intensified competition rather than through any demonstration or imitation effects which might be encouraging the spread of open innovation. Our findings highlight the social benefits of openness over and above the direct benefit of open innovation to firms' own innovation productivity.

2. Conceptual framework: externalities of openness in innovation

Knowledge spillovers may have important effects on productivity as knowledge created in one firm or organisation spreads to, and is used by, other firms. Research examining such knowledge spillovers has grown rapidly over the last two decades with a focus on the sectoral or spatial aspects of R&D spillovers (Jaffe, 1986; Jaffe et al., 1993; Bloom et al., 2012), and spillovers associated with firms' proximity to multinational enterprises (Aitken and Harrison, 1999; Javorcik, 2004).[2] Two rather different approaches to capturing knowledge spillovers are evident in the innovation and industrial economics literatures. First, and most common, are empirical papers which adopt a micro-econometric approach to investigating spillover effects on productivity, capturing spillover effects by including industry or regional R&D or ownership indicators as explanatory variables in augmented production functions. The basic argument here is that firms operating in, say, sectors with higher average R&D spend may benefit from informal knowledge spillovers and therefore have higher productivity. The empirical evidence is rather mixed, however, both about the magnitude of such 'pure' knowledge spillover effects and, in the case of FDI spillovers, also about the actual presence of any significant knowledge spillovers.

A second and smaller group of more recent papers adopts a different conceptual and empirical approach, relating knowledge spillovers more directly to firms' innovation partnering arrangements with customers, suppliers, etc. (Crespi et al., 2008; Jirjahn and Kraft, 2011; Czarnitzki and Kraft, 2011; Vahter, 2011). Here, the basic argument is that knowledge generated (or acquired) by one firm may spill over to, and benefit, other firms through their innovation partnerships. Interest in the importance of such partnering arrangements for innovation, and related externality effects, has been stimulated by discussion of open innovation (Dahlander and Gann, 2010). Despite the fact that the open innovation literature stresses the role of external linkages, studies looking at the potential benefits of the adoption of open innovation have, to date, focussed purely on the private benefits of openness (Love et al., 2011; Laursen and Salter, 2006; Leiponen and Helfat, 2010) and have not investigated the potential for wider social benefits.

Here we suggest a third mechanism through which externalities may occur from an open innovation process, reflecting the social benefits of firms' adoption of open innovation. Specifically, we argue that openness itself – for any given scale of R&D inputs or innovation outputs – may generate positive externalities which extend beyond the organisations involved in any specific innovation partnership. We thus suggest that even where, for example, the average level of R&D or other knowledge-creation investment remains unchanged, an increase in the average degree of openness in a sector may result in beneficial externalities which may raise the innovation productivity of the sector.

Such externalities of openness might work in three rather different ways, reflecting to some extent related arguments about the mechanisms which mediate R&D spillovers. First, externalities of openness may arise from extensive knowledge diffusion in sectors in which technology has some of the characteristics of a public good, and/or sectors which are more densely networked. Where technology has the characteristics of a quasi-public good, levels of ambient knowledge or intelligence are likely to be greater (Sadri, 2011), providing the basis for more widespread knowledge application and use (Kovacs et al., 2006). Tassey (2005), for example, argues that knowledge created by firms' research labs, government labs and universities may have some of the attributes of a quasi-public good, and play a significant role in enabling the development of proprietary technologies. Diffusion of such knowledge may be mediated through mechanisms such as social interaction or inter-personal networks, trade publications, professional associations etc. or through firms' direct links with knowledge brokers such as consultants or intermediary institutions.

Knowledge diffusion may also be greater where spatially bounded or concentrated networks facilitate 'buzz', or intensive face-to-face interaction between network members (Breschi and Lissoni, 2009; Ibrahim et al., 2009; Storper and Venables, 2004). In particular, in knowledge intensive industries, the importance of buzz and face-to-face interaction have been emphasised to the diffusion of tacit knowledge or emerging knowledge which has yet to be codified (Asheim et al., 2007). Combinations of buzz and the availability of knowledge which has quasi-public characteristics may be particularly powerful in generating positive externalities of openness, raising firms' innovation productivity above that suggested by their private investments in knowledge creation and external search.

The second group of mechanisms through which externalities of openness might occur relate to imitation and demonstration effects similar to those suggested in the technology adoption literature (Hofmann and Orr, 2005; Rao and Kishore, 2010). Here, we envisage that externalities of openness may arise as firms respond to openness in the sector by becoming more open themselves. This in turn is likely to have positive innovation productivity effects. Firms in the proximity of open innovators, for example, may observe the innovation value of openness, and therefore be more inclined to increase their own level of openness. Similarly, labour mobility may spread an awareness of the benefits of openness as employees move between firms or establish new companies. As with the knowledge diffusion mechanism this type of adoption effect is likely to be stronger where sectors are strongly networked and firms are geographically proximate.

Finally, in addition to these knowledge transfer and adoption effects, the proximity of open innovators may also have externality effects through competition (Bloom et al., 2012). The competition effect itself can be divided into two. First, there may be a 'market

[2] See Görg and Greenaway (2004) for a literature review on FDI spillovers.

stealing' effect, which results in negative consequences for innovation performance and productivity. Firms located in sectors where innovation partner networks are dense may lose out if other firms are more strongly networked and therefore find it cheaper and easier to find suitable external knowledge. This suggests the potential for negative externalities from openness to reduce the innovation value of firms' innovation inputs where levels of sectoral openness are high. In the longer run, however, similar factors may have positive competition effects due to the competitive pressure created by open innovators.[3] Tougher competition from open innovators may increase a firm's own incentive to invest in innovation inputs or become more open (Aghion and Griffith, 2005; Aghion et al., 2009; Leibenstein, 1966; Vickers, 1995). This would result in longer-term improvements in innovation productivity. The strength of this type of competition effect will, however, depend on how far the particular firm is from its competitors in terms of innovation performance and level of knowledge/technology.[4]

In conclusion, externalities of openness may work through a number of channels. Knowledge diffusion and adoption effects are expected to be positive but may be offset by market stealing competition effects. As a result the net effects of any externalities of openness remains an empirical issue. Therefore we now turn to an empirical estimation of the direction and scale of externalities in openness in the case of Irish manufacturing.

3. Data and methods

Our empirical analysis is based on plant-level panel data taken from the Irish Innovation Panel (IIP) covering the period 1994–2008. The IIP provides information on the innovation activities of manufacturing plants in Ireland and Northern Ireland. It consists of five consecutive surveys conducted every three years using common questions, and capturing the same indicators of open innovation during the period. The initial IIP survey used here was conducted between November 1996 and March 1997. It covered plants' innovation indicators for the 1994–1996 period, and had a response rate of 32.9%. The next IIP survey covered the 1997–1999 period and reached a response rate of 32.8%. The third survey covering the 2000–2002 period achieved an overall response rate of 34.1%. Subsequent surveys covering the 2003–2005 and 2006–2008 periods achieved response rates of 28.7% and 38%. The resulting panel is unbalanced, due both to the entry and exit of plants and survey non-response.

Analysis carried out at the plant level rather than the firm level has some advantages. Although strategic decisions may be made at the firm level, they are implemented at the level of the individual plant, and are likely to be based on the product market situation faced by individual plants. This is especially true of large multi-product enterprises. Thus a firm may use one set of external linkages at one plant and a quite different set at another which is facing a different set of market circumstances, a subtlety which may be missed in firm-level analysis. In practice, single plant firms make up most of the sample: 58% of all observations in the IIP are from single-plant firms. To allow explicitly for the role of plants which are part of a larger group we include a number of control variables which are detailed below.

One question asked in each of the different waves of the IIP was: '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 such 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 were identified in the survey questionnaire: linkages to customers, suppliers, competitors, joint ventures, consultants, universities, industry operated laboratories, and government operated laboratories. As could be expected, the most common external partners in plants' innovation process are its customers and suppliers (see also Love et al., 2011). Links to universities, labs, competitors and other partners are much less common, especially in the case of smaller firms (see Vahter et al., 2011). Note that 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.[5]

Our econometric analysis is based on estimation of the innovation or knowledge production function (Crépon et al., 1998; Laursen and Salter, 2006; Love et al., 2011) with plants' innovation linkages and indicators intended to capture potential externalities of openness included among other standard explanatory variables. As the dependent variable in the innovation production function we use two widely applied innovation output indicators: (i) 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 and (ii) a product innovation dummy. The first dependent variable reflects plant's ability to introduce new or improved products to the market and their short-term commercial success. The second variable shows the propensity to engage in innovation. Using the two variables allows us to test whether externalities of openness have different effects on the propensity and intensity of innovation.

Estimating externality effects raises a number of conceptual and econometric difficulties. One important issue in estimating externalities of openness is whether firm or plant-level indicators of linkages (linkages to competitors, suppliers, clients, etc.), and therefore the breadth of linkages at firm level, can themselves be seen as proxies of such externalities, or whether such externalities are better measured by the inclusion of sector-level measures of openness. Practice in the literature varies on this issue. The open innovation literature (Chesbrough, 2003a,b, etc.) has concentrated on the private benefits to firms from their adoption of open innovation. It does not address the issue of whether and to what extent the standard measures of linkages at firm level represent market-based transactions with other firms, or if they instead capture knowledge spillovers from other firms that have opted for an open innovation strategy. However, some papers on innovation and knowledge linkages published in the economics literature have treated firm-level indicators of external linkages as indicators of spillovers from other firms (e.g. Czarnitzki and Kraft, 2011; Jirjahn and Kraft, 2011). In addition, in a paper on knowledge spillovers Crespi et al. (2008) treat the CIS data on linkages measured at firm level as a potential indicator of spillovers. However, they at least show that their standard measure of (FDI) spillovers is correlated with some of the firm level measures of linkages to other firms.

[3] Note that this effect is distinct from the knowledge transfer effect described before: it does not require inter-firm knowledge transfer.

[4] Based on endogenous growth models as outlined in Aghion et al. (2009) and Acemoglu et al. (2006) we would expect that tougher competition has positive effects on firm's performance, innovation incentives and innovation activities if the firm is sufficiently close to the technology frontier. There are positive effects on innovation of these relatively high-performing firms as they can escape adverse effects of competition by innovating. However, we would also expect, based on the same models from economics, that if the firm is far from the technology frontier of the sector, then the tougher competition will reduce its innovation incentives, as it has little hope of surviving the tougher competition. Thereby, competition will have also negative effect on its innovation performance and productivity growth.

[5] 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).

We argue here that one cannot conclude that standard firm-level, survey-based measures of linkages show either *only* information about market-based transactions with other firms or *only* information on spillovers. Researchers almost never observe the prices paid for knowledge transfer through links with other firms, and therefore it is usually not possible to determine from the standard survey responses which of these two effects are covered by the standard firm-level indictors of linkages. In practice – and especially in the absence of any other explicit measure of spillovers – we believe these firm-level variables can reflect both effects, with the extent of such linkages providing one mechanism through which the adoption and competition effects of externalities of openness might work. In our analysis we therefore include standard plant-level measures of the breadth of innovation linkages (as used in Laursen and Salter, 2006, etc.), and interpret the coefficients as potentially reflecting both market-based and spillover effects. However, we also include in the innovation production functions a sectoral indicator of openness explicitly designed to capture externality effects not mediated through plants' own external linkages. A significant coefficient on this variable would indicate (provided that we have suitable instruments) the existence of externalities of openness from firm's peers to the firm itself through either knowledge diffusion or buzz effects. We regard this as an improvement over the knowledge spillovers studies of Jirjahn and Kraft (2011) or Czarnitzki and Kraft (2011), because it permits a more direct test of the spillover effects of external linkages, by concentrating on information about the linkages of firm's peers in the same sector.

Econometrically, the issues raised with estimating externality effects have been examined in the classical discussion of the endogeneity and reflection problems and other related estimation problems in Manski (1995), Angrist and Pischke (2009) and Bloom et al. (2012). The key issue is the potential endogeneity of openness at sector level and the unobserved heterogeneity that can affect the results of econometric analysis and their interpretation. Usually, we cannot be sure whether the coefficient on a spillover variable in a simple innovation model shows the effect of spillovers, or whether more innovative firms are simply more likely to be in sectors with higher openness for reasons fully unrelated to the openness of their peers. Some unobserved variables (e.g. managerial ability and experience, attitudes of managers and owners etc.) may determine both the extent of openness in a sector and the sector's innovativeness.

To minimise this type of issue here we use an instrumental variables approach to reduce any issues with the potential endogeneity of the sectoral externalities of openness measure. Let $INNOV_{it}$ be an innovation output indicator (for plant i at survey period t), and X_{it} a vector of commonly used plant level control variables. OI_{it} represent plants' own breadth of innovation linkages, and therefore in our data takes a value between 0 and 8. EXO_{it} is the sectoral proxy for externalities of openness in innovation. It is calculated as the average breadth of innovation linkages among each plants' peers in its industry (within 2-digit sectors). Note here that for each plant its own breadth of linkages is excluded from the calculation of this sector level average of its peers' linkages. This way we have a more direct test of potential spillovers: we do not double-count the own-plant effect of linkages, as plant's own breadth of linkages is already included as a separate control variable in Eq. (1). Several earlier studies have clearly shown the importance of firm's own breadth of linkages for innovation performance (Laursen and Salter, 2006; Leiponen and Helfat, 2010; Love et al., 2011).

The innovation production function with sector specific (λ_j) and time effects (τ_t) can in our analysis be written as:

$$INNOV_{it} = \delta_0 + \delta_1 OI_{it} + \delta_2 EXO_{it} + \delta_3 X_{it} + \lambda_j + \tau_t + \varpi_{it} \qquad (1)$$

Here, i denotes the plant, t period (IIP wave), and j sector, ϖ_{it} is an idiosyncratic error term. Our choice of estimation approach for Eq. (1) reflects the form of our main dependent variables. Therefore in our main specification, where the dependent variable is the share of new or improved products in sales (0–100%) we use a panel IV-Tobit model. The estimated equation includes a set of sector indicators at the 2-digit level and a series of time dummies. In addition, we check whether spillovers affect the propensity to engage in product innovation by using an IV-probit model to estimate Eq. (1) with a product innovation dummy as the dependent variable. The effects on propensity of innovation may be different from the effects on intensity of innovation performance.

A key issue in the estimation is the choice of appropriate instruments for the sector level externality measure. Ideally, one needs a set of instruments that predicts variation in the sector-level externality measure but is unrelated to changes in individual firm's innovation performance, after controlling for other relevant factors. As instruments for the average breadth (i.e. number) of different types of knowledge linkages in each (2-digit) sector of Irish manufacturing we use the average sector-level breadth of knowledge linkages of other Western European countries. The breadth of linkages or knowledge sources elsewhere in Europe may be a good predictor of Irish sector-level breadth of linkages as this measure is likely to be correlated at sector level across European countries because the sector level drivers of openness may be similar across countries.[6] We use data on breadth of knowledge sourcing (number of different types of knowledge sources that were of high importance for the firm) from the 3rd, 4th and 6th (CIS2008) Community Innovation Survey from Belgium, Germany, Portugal, Spain and Norway to calculate this instrument.[7] In doing so we also experimented with using the same sector-level indicator from individual Western European countries: the econometric results remain similar in this case. In addition, we employ Irish sector-level data about importance of lack of partners for calculating an additional instrument. We calculate sector-level average perception of the importance of lack of partners as an impediment to innovation of firms in the sector. This variable could be expected to be negatively associated with sector-level breadth of linkages. We also assume here that it affects the outcome variable only through its effects on sector-level extent of knowledge linkages.

To be a valid instrument we must be confident that average sectoral openness in Europe is unlikely to have large effects on Irish firms' innovation through channels other than similarities in sector-level drivers of openness. One possibility is that such an effect may occur because breadth of knowledge linkages in Europe

[6] Haskel et al. (2007) and Vahter (2011) have used a similar approach to find instruments for the study of FDI spillovers.

[7] We owe thanks to the EU Service-Gap project team (esp. Prof Mary O'Mahony) at the University of Birmingham for enabling us to calculate these variables based on the EUROSTAT anonymised micro dataset of CIS surveys in Europe. We have chosen to use data from these other Western European countries for which we have infromation about knowledge sources in the three waves of the CIS. In the case of CIS3 and CIS4 we have data about importance of knowledge sources from all five countries, in the case of CIS2008 we can include Spain, Potugal and Germany in calculation of the sector level instrument. CIS3 covers years 1998–2000, CIS4 2002–2004, CIS2008 2006–2008. In our econometric analysis based on the IIP we cover period 1994–2008. The values of instruments for the period 1994–2002 are calculated based on CIS3, for the period 2003–2005 based on CIS4, for the period 2006–2008 based on CIS2008. There are ten different knowledge sources outlined in the CIS questionnaires, including knowledge sourcing from clients, suppliers, competitors, universities, etc. We define for each knowledge source a dummy that takes the value 1 if this source is highly important for the innovation process of the firm. The breadth of different knowledge sources is calculated as a sum of these dummy variables, and takes values between 0 and 10. Using each firm's breadth indicator we calculate an average Western European breadth of linkages in each 2-digit manufacturing sector (i.e. in ten different sectors).

may reflect technological opportunities at sectoral level which also apply to Ireland, and these technological opportunities may in turn have an effect on Irish innovation at the micro level.[8] While we feel that this somewhat indirect effect is unlikely to play a major role, we do attempt to allow for it empirically. The term 'technological opportunity' is not terribly well defined,[9] nor are suitable proxies always obvious. Jaffe (1986) uses relatively simple 'technological cluster' dummies, based around high- and low-tech sectors. In our estimations we too allow for technological opportunity by using a simple hi-tech dummy variable: we also employ a number of sectoral variables to allow for aspects of competitive conditions both at home and internationally, which may be expected to pick up to some extent general technological opportunity effects.[10]

Even when instrumented, the openness externality term may in part capture knowledge produced within the sector rather than spillovers from openness. We therefore include in the estimation a measure of sectoral average R&D intensity to allow for this effect. We include in each model a set of controls for other plant characteristics which have been found in previous studies to affect innovation outputs. One of these is an indicator of whether or not plants are doing in-house R&D (Crépon et al., 1998; Oerlemans et al., 1998). This may directly drive innvoation through knowledge creation but can also be seen as an indicator of absorptive capacity (Cohen and Levinthal, 1989). We also include variables intended to reflect the ownership and strength of plants' internal knowledge base, multinationality, age and size of the plant (Klette and Johansen, 1998). A foreign ownership dummy is incorprated as a control variable because links between plants within a multinational are a potentially important channel for international knowledge transfer (Lipsey, 2002) and thus can affect innovation performance. Foreign-owned firms may be more able to benefit from open innovation than domestic firms due to access to knowledge resources within the multinational's knowledge network. Multinationality may also be an indicator of the higher absorptive capacity of the plant. In addition, we include an indicator of labour quality. This is the share of each plant's employees which have some degree level qualification (Freel, 2005). As with R&D, this variable may also be seen as reflecting the absorptive capacity of the plant. The estimated 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 included as a broad proxy for local competition (at the 2-digit level). In a reference to Geroski (1995), we include a proxy for the expected profits from innovating as this would affect the incentive to engage in innovation. This proxy is calculated for each firm as its distance from the average profitability (price-cost margin) of innovators of the particular sector of manufacturing industry. Larger values of this variable indicate the firm's greater distance from the profitability of innovators of the sector.

Descriptive statistics are shown in Table 1.

4. Econometric results

Tables 2 and 3 summarize our results on the externalities of openness in innovation. As argued above, this variable may be endogenous and therefore may need to be instrumented. Indeed, the Wald test of exogeneity of the spillover variable rejects the exogeneity assumption (with *p*-value of 0.01, in the case of Model 2 in Table 2). In order to account for the endogeneity of our measure for openness spillovers we need instruments that predict changes in the spillover proxy (sector-level average breadth of linkages), but at the same time are uncorrelated with the error term in Eq. (1) (i.e. do not affect the dependent variable through channels other than the spillover proxy).

Table 2 provides the Tobit estimates, with sales from new or improved products as the dependent variable. We show both the results of estimating a standard Tobit and the IV versions of the Tobit model, using each instrument separately as well as jointly for maximum transparency. The control variables include standard firm-level inputs in innovation process and also a set of time-varying sector-level variables, like the Herfindahl index, trade openness, FDI share in a sector, trade growth and also expected profits from innovating. The sector-level variables, together with time dummies and sector dummies, capture the effects of changes in the economic environment and sector-specific differences between them.

A general conclusion that we can draw based on all models in Table 2, regardless of whether we consider the IV or the standard Tobit model, is that the presence of firms that have a large range of knowledge linkages appears to benefit other firms in the same sector in terms of innovation productivity. The econometric evidence clearly suggests the presence of externalities of openness, even after accounting for other sector or time-specific effects and other controls. It is also evident that instrumenting matters, changing the estimates of the strength of any externalities to a significant extent. In the standard Tobit model a one unit increase in the average breadth of linkages of other firms in a sector is associated on average with a 3.2% higher share of sales from new or modified products. Accounting for potential endogeneity in our externality measure, then the effect is markedly larger. Now a one unit increase in the average breadth of sectoral linkages is associated with an 18–28% higher innovation performance at the firm level. An externality effect of this magnitude is in fact plausible. We have to recall that the average breadth of linkages at sector level is 1.18 and its maximum at sector level is only 2.3 (Table 1), and so a one unit increase in our sector-level spillover

Table 1
Descriptive statistics.

Variable	Mean	Std. dev.
Sales from new or improved products (%)	24.388	29.929
Product innovation dummy	0.644	0.479
R&D conducted in-house	0.483	0.500
Breadth of linkages (0–8)	1.180	1.780
Employment (no.)	100.367	271.194
Establishment age (years)	30.096	30.152
Externally-owned	0.294	0.456
Workforce with degree (%)	10.142	13.672
Govt. support for product innovation	0.235	0.424
Expected profits from innovating	0.006	0.209
Herfindahl index (2-digit level)	0.270	0.124
FDI employment share (0–1) in the sector	0.524	0.269
Trade as a ratio to output	0.596	0.341
Export growth, y–o–y (%)	6.720	15.065
Sector level R&D expenditures per employee	1.113	1.498
'High-tech' sector dummy	0.312	0.464
Open innovation spillover	1.182	0.362
Sector level average breadth of knowledge sources in other Western European countries	0.841	0.423
Sector level average of importance of lack of partners as barrier to innovation (1–5)	1.863	0.203
Number of observations	3581	

Source: IIP, 1994–2008.

[8] We are grateful to an anonymous referee for pointing out this possible mechanism.

[9] Jaffe (1986) defines the term as "exogenous, technologically determined variations in the productivity of R&D" (p. 996), while Klevorick et al. (1995) prefer "the set of possibilities for technological advance" (p. 188).

[10] As Klevorick et al. (1995) points out, the purpose of examining technological opportunity is to help explain why R&D intensity is high in some sectors and low in others. In other words, technological opportunity helps determine sectoral R&D intensity. By allowing for sectoral R&D intensity we also further allow (indirectly) for the underlying technological opportunity.

Table 2
Effects of openness in innovation on innovation performance, IV-Tobit results.

Dependent variable: sales from new or improved products (%)	(1) Model 1(Tobit)	(2) Model 2 (IV-Tobit)	(3) Model 3 (IV-Tobit)	(4) Model 4 (IV-Tobit)
Open innovation spillover	3.180**	27.901***	22.110***	18.308***
	(1.271)	(8.077)	(5.968)	(6.947)
R&D conducted in-house	31.427***	31.234***	31.548***	31.755***
	(0.772)	(0.879)	(0.827)	(0.845)
Own breadth of linkages (0–8)	4.354***	4.301***	4.312***	4.318***
	(0.213)	(0.215)	(0.214)	(0.214)
Employment (no.)	0.010***	0.005	0.006	0.006*
	(0.004)	(0.003)	(0.003)	(0.003)
Employment squared	−0.027***	−0.021*	−0.021**	−0.021**
	(0.009)	(0.009)	(0.009)	(0.009)
Establishment age (years)	−0.100***	−0.096***	−0.096***	−0.097***
	(0.013)	(0.012)	(0.012)	(0.012)
Externally-owned	5.975***	6.568***	6.577***	6.581***
	(0.900)	(0.871)	(0.867)	(0.865)
Workforce with degree (%)	0.242***	0.232***	0.227***	0.223***
	(0.029)	(0.029)	(0.029)	(0.029)
Govt. support for product innovation	8.456***	9.137***	9.223***	9.273***
	(0.860)	(0.875)	(0.868)	(0.867)
Expected profits from innovating	−1.331	1.300	1.143	0.991
	(1.609)	(1.652)	(1.636)	(1.637)
Expected profits from innovating squared	−1.111	−5.758	−4.541	-3.762
	(3.420)	(3.894)	(3.711)	(3.776)
Herfindahl	−10.167***	−25.623***	−22.337***	−20.125***
	(3.021)	(5.529)	(4.531)	(5.017)
Sector level R&D intensity	1.463***	0.941***	1.019***	1.071***
	(0.307)	(0.338)	(0.328)	(0.331)
'High-tech' sector dummy	3.626***	−2.307	−1.127	−0.351
	(1.355)	(2.083)	(1.760)	(1.901)
FDI employment share (0–1) in the sector	10.626***	12.926***	12.725***	12.612***
	(1.507)	(1.573)	(1.556)	(1.558)
Trade as a ratio to output	−3.263*	−8.957***	−7.042***	−5.787**
	(1.664)	(3.080)	(2.499)	(2.755)
Export growth, y–o–y (%)	−0.142***	−0.204***	−0.193***	−0.186***
	(0.031)	(0.035)	(0.034)	(0.034)
Region (NUTS3) dummies	Yes	Yes	Yes	Yes
Period dummies	Yes	Yes	Yes	Yes
Constant	−8.225***	−27.074***	−23.143***	−20.578***
	(2.065)	(5.761)	(4.423)	(5.031)
Instruments in the 1st stage of the IV-Tobit: (Dep. Var. is OI spillover)				
Sector level average breadth of knowledge sources in other Western European countries		0.179***	0.13***	
		(0.009)	(0.009)	
Sector level average of importance of lack of partners as barrier to innovation (1–5)			0.277***	0.338***
			(0.015)	(0.014)
Other controls		Yes	Yes	Yes
Region (NUTS3) dummies		Yes	Yes	Yes
Period dummies		Yes	Yes	Yes
Number of excluded instruments	–	1	2	1
F-test of excluded IVs from a 2SLS specification		74.44 ($p = 0.000$)	55.93 ($p = 0.000$)	67.43 ($p = 0.000$)
Stock–Yogo weak ID critical values:				
Maximal 10% allowed IV bias		16.38	19.93	16.38
Maximal 15% allowed IV bias		8.96	11.59	8.96
Maximal 20% allowed IV bias		6.66	8.75	6.66
Sargan over-identification test		–	1.864 ($p = 0.172$)	–
Observations	2619	2619	2619	2619
Log likelihood	−5.31e+04	−5.48e+04	−5.46e+04	−5.47e+04

Notes: Instrumental variables Tobit model. Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Dependent variable: sales from new or improved products (%). Period: 1994–2008, waves 2–6 of the IIP.

proxy is in fact a massive increase in openness at the sectoral level. Also note that an increase in the sector-level presence of open innovators may affect a large set of firms and thus a large set of knowledge sources and co-operation partners. By comparison, the effect of adding one additional type of linkage by the firm itself is associated with around 4.3% higher innovation output. Other firm-level controls have their expected signs and magnitudes. R&D, foreign ownership, skill intensity and government subsidies to innovation are positively and strongly associated with higher innovation productivity. Once other controls are accounted for, the effect of expected profits is not significant in Table 2. As anticipated, sectoral R&D intensity is highly significant and positive: the technological opportunity dummy is significant in the initial tobit estimations, but not in the IV estimations, suggesting that technological opportunity does not directly account for variations in innovation once other factors are allowed for.

Table 3
Effects of openness in innovation on innovation performance, IV-probit results.

Dependent variable: product innovation dummy	(1)	(2)	(3)
Marginal effects	Model 1 (IV-probit)	Model 2 (IV-probit)	Model 3 (IV-probit)
Open innovation spillover	0.093*	-0.011	0.154*
	(0.054)	(0.075)	(0.061)
R&D conducted in-house	0.307***	0.313***	0.302***
	(0.007)	(0.006)	(0.008)
Own breadth of linkages (0–8)	0.052***	0.052***	0.052***
	(0.002)	(0.002)	(0.002)
Employment (no.)	6.05E−05	6.83E−05	5.72E−05
	(0.00004)	(4.26E−05)	(4.24E−05)
Employment squared	−0.0001	9.48E−09	8.83E−09
	(0.0002)	(1.81E−08)	(1.79E−08)
Establishment age (years)	0.0003***	0.0002*	0.0003**
	(0.0001)	(0.0001)	(0.0001)
Externally-owned	0.086***	0.086***	0.085***
	(0.008)	(0.008)	(0.008)
Workforce with degree (%)	0.002***	0.001***	0.002***
	(0.0002)	(0.0003)	(0.0002)
Govt. support for product innovation	0.135***	0.137***	0.133***
	(0.009)	(0.009)	(0.009)
Expected profits from innovating	−0.024	−0.027*	−0.022*
	(0.015)	(0.015)	(0.015)
Expected profits from innovating squared	−0.2***	−0.178***	−0.211***
	(0.034)	(0.037)	(0.035)
Herfindahl	−0.151***	−0.090*	−0.187***
	(0.040)	(0.051)	(0.043)
Sector level R&D intensity	0.016***	0.018***	0.015***
	(0.003)	(0.003)	(0.003)
‘High-tech’ sector dummy	−0.076***	−0.055***	−0.878***
	(0.159)	(0.019)	(0.017)
FDI employment share (0–1) in the sector	0.073***	0.070***	0.075***
	(0.014)	(0.014)	(0.014)
Trade as a ratio to output	0.009	−0.043	−0.011
	(0.023)	(0.028)	(0.025)
Export growth, y–o–y (%)	−0.002***	−0.002***	−0.002***
	(0.000)	(0.000)	(0.000)
Region (NUTS3) dummies	Yes	Yes	Yes
Period dummies	Yes	Yes	Yes
Number of excluded instruments	2	1	1
Excluded instruments	Sector level average breadth of knowledge sources in other Western European countries; sector level average of importance of lack of partners as barrier to innovation (1–5)	Sector level average breadth of knowledge sources in other Western European countries	Sector level average of importance of lack of partners as barrier to innovation (1–5)
Observations	2759	2759	2759
Log likelihood	−9878.5	−10,069.0	−9974.3

Notes: Instrumental variables probit model. Marginal effects reported at sample means. Standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Dependent variable: product innovation dummy (%). Period: 1994–2008, waves 2–6 of the IIP.

We can observe that both instruments used in our analysis are strong ones (see lower panel of Table 2). The *F*-statistic of these variables in the first stage regression of sector level openness on the instruments is high, and is significantly above the Stock–Yogo critical values (Stock and Yogo, 2005). Also, Model 3 in Table 2 with two instrumental variables is not over-identified, as shown by the result of the Sargan test. However, the sign of the additional instrument – sector level average of importance of lack of partners as barrier to innovation – is counter-intuitive. The higher perception of lack of partners in a sector is associated with larger, not smaller, number of different knowledge linkages. The counter-intuitive sign of lack of partners may at first glance seem odd. But it may reflect the earlier findings in Loof (2009) and others that more innovative firms are more likely to report higher innovation barriers as they are more able to perceive them and more likely to have encountered barriers due to their higher intensity of innovation activities. However, the correlation of our key explanatory variable with the CIS-level instrument is exactly as expected. It seems that the CIS-based instrument is a more suitable instrumental variable; it is more likely to be a valid instrument than sector level lack of partners. The IV results are rather similar in different specifications of the IV-Tobit model in Table 2: changes in the set of instruments affects the end result only a little. Instrumenting itself, however, is crucial to the estimated scale of the externalities of openness effect although not its statistical significance.[11]

Next we check whether the significant results on the externalities of openness are also reflected in the data on the propensity to

[11] Evidence on the likely suitability of our chosen instrumental variables is included in the Annex to this paper which reports the correlation table between the innovation performance variables, the excluded instruments, and other controls in the regression analysis. As the correlation table suggests, there is significant correlation between the excluded instruments and the key endogenous variable (open innovation spillovers). At the same time, there are low correlations between the excluded instruments and our indicators of innovation performance. This combination suggests the suitability of our chosen instruments.

Table 4
Effects of open innovation spillovers on breadth of linkages of firms.

Dependent variable: breadth of linkages (0–8)	(1) Model 1 (IV, 2SLS)	(2) Model 2 (ZINB, intensity equation)	(2) Model 2 (ZINB, inflation equation)
Open innovation spillover	0.108	0.119	0.051
	(0.116)	(0.081)	(0.184)
R&D conducted in-house	0.581***	0.160***	−0.843***
	(0.067)	(0.049)	(0.103)
Employment (no.)	−0.440***	0.057	0.404
	(0.148)	(0.089)	(0.263)
Employment squared	0.091***	0.008	−0.077**
	(0.018)	(0.010)	(0.032)
Establishment age (years)	−0.000	−0.001	−0.000
	(0.001)	(0.001)	(0.002)
Externally-owned	0.209***	0.015	−0.339***
	(0.077)	(0.049)	(0.119)
Workforce with degree (%)	0.006**	0.001	−0.011**
	(0.003)	(0.002)	(0.005)
Govt. support for product innovation	0.744***	0.206***	−0.691***
	(0.077)	(0.043)	(0.116)
Expected profits from innovating	0.086	−0.014	−0.061
	(0.146)	(0.086)	(0.228)
Expected profits from innovating squared	1.144***	0.415**	−0.741
	(0.331)	(0.169)	(0.515)
Herfindahl	0.350	−0.276	−1.001*
	(0.277)	(0.208)	(0.456)
Sector level R&D intensity	−0.027	−0.001	0.063
	(0.028)	(0.017)	(0.043)
'High-tech' sector dummy	0.004	−0.169**	−0.354*
	(0.115)	(0.079)	(0.184)
FDI employment share (0–1) in the sector	−0.230*	−0.036	0.238
	(0.131)	(0.082)	(0.207)
Trade as a ratio to output	−0.072	−0.112	0.302
	(0.142)	(0.092)	(0.219)
Export growth, y–o–y (%)	0.005*	0.001	−0.007*
	(0.003)	(0.002)	(0.004)
Region (NUTS3) dummies	Yes	Yes	Yes
Period dummies	Yes	Yes	Yes
Constant	0.585*	0.287	0.955
	(0.345)	(0.233)	(0.588)
Number of excluded instruments	2	–	–
Excluded instruments	Sector level average breadth of knowledge sources in other Western European countries; sector level average of importance of lack of partners as barrier to innovation (1–5)	–	–
Observations	2765	2765	2765
Log likelihood		−3609.2	–

Notes: 2SLS and zero-inflated binomial model. Dependent variable: breadth (number) of different types of knowledge linkages (0–8). Standard errors are in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$ (%). Period: 1994–2008, waves 2–6 of the IIP.

innovate (Table 3). We estimate IV-probit models, with exactly the same first stage as in Table 2. Unlike the previous estimation, there is little clear evidence of externalities from openness. The results show significant and marginally positive coefficients of the externality measure only in Models 1 and 3, where lack of partners at sector level is the instrument used, and this is significant only at the 10% level. Here the increase of breadth of linkages at sector-level by one unit is associated with between 9% and 15% higher propensity that a firm from the same sector engages in innovation. When the (preferred) CIS instrument is used (Model 2) the externality coefficient is insignificant. Externalities of openness appear to operate principally by increasing firms' innovation intensity rather than by making firms more likely to innovate.

5. Extension – the channels of externality effects

It has been suggested that externalities in the innovation process can work in a number of ways – through informal knowledge spillovers, through firms' own linkages (Crespi et al., 2008; Czarnitzki and Kraft, 2011) and through the type of externalities of openness discussed earlier. In the previous section we examined externalities of openness separately from firms' own innovation partnering arrangements. A clear possibility, however, is that through a demonstration, imitation or competition effect sectoral openness may also impact on firms' own breadth of knowledge linkages. To evaluate the importance of this effect we estimate a model in which the dependent variable is the breadth of firms' different external knowledge linkages, which is regressed on our externality measure and other plant-level controls.

We estimate Eq. (2) to investigate this component of the externalities of openness, where OI_{it} denotes firm's own breadth of external knowledge linkages, OXI_{it} is the same externality measure as in Eq. (1). Again, we exclude each firm's own breadth of linkages from the calculation of this variable.

$$OI_{it} = \alpha_0 + \alpha_1 OXI_{it} + \alpha_2 X_{it} + \varphi_j + \kappa_t + \psi_{it} \quad (2)$$

Eq. (2) includes sector effects (at 2-digit sector level), time effects, other control variables (similar to the ones in Eq. (1)) and an idiosyncratic error term. It is important to stress that one would not be able to estimate the causal relationship in Eq. (2) if the calculation of the spillover proxy included firm's own breadth of linkages. In a bivariate regression of firm's own openness on the sector level average openness, the coefficient of spillover variable would always be positive and equal to 1 (see Angrist and Pischke, 2009, p. 195), and would indicate nothing about causality. It is therefore crucial to exclude firm's own breadth of linkages from the calculation of the sector-level average. However, even then the relationship in Eq. (2) may be affected by the so-called Manski 'reflection problem' (Manski, 1995), as the simultaneous changes in sectoral breadth of linkages and plant's own indicator of breadth of linkages may show a causal effect of the latter, but this may simply reflect some common external stimulus or shock which affect all firms in a sector, thereby inducing a spurious positive correlation between the two variables. We note that while we alleviate the reflection problem by using instrumental variables for the spillover proxy, it may still be an issue in Eq. (2) if the shock is a general Europe-wide sector-level shock that affects also the breadth of linkages in the rest of Western Europe. Since in Eq. (1) the dependent variable and the spillover proxy are not the same, the reflection problem is unlikely to be a major issue in that estimation. Eq. (2) we regard as more speculative, and provides additional evidence about one particular potential channel of spillovers.

Results are shown in Table 4. Since the dependent variable takes a value between zero and eight (breadth of linkages), we use zero-inflated negative binomial estimation. The clear result from both un-instrumented zero-inflated negative binomial model and the 2SLS model is that openness of firm's peers is not associated with higher openness of the firm itself, once the firm has any external linkages. The evidence of Table 4 clearly suggests that externalities of openness are not working through adoption effects which influence firms' own openness; instead these externalities appear to be enhancing innovative sales alongside firms' own openness through either a knowledge diffusion or competition effect. The results in Tables 2 and 4 also point to the fact that we should be very cautious in equating firm-level measures of linkages with knowledge spillovers. In fact, based on data from Ireland we conclude that firm-level indicators of openness (breadth of linkages) are not a valid measure of spillovers of open innovation in Irish manufacturing industry. Our results imply that the findings in Jirjahn and Kraft (2011) or Czarnitzki and Kraft (2011) that concentrate on individual firms' linkages misinterpret these as spillovers when instead they are more likely to result from direct and market-based effects. Externalities of openness occur in addition to firms' own linkages.

6. Conclusions

This paper provides econometric evidence of positive externalities from openness in innovation. However, there seems to be no indication that such externalities work through increasing the adoption of open innovation practices. Instead, these externalities appear to work through other channels related to knowledge diffusion or competition effects. We would stress, however, that our findings must be regarded as preliminary at this point. We deal only with 'inbound' aspects of open innovation, and examine only one indication of openness – the breadth of firms' innovation linkages. In addition, our analysis is restricted to a single country, albeit over a relatively long time period. Nevertheless, our findings appear to suggest that there are important benefits from openness to external knowledge beyond those hitherto identified. If, as our results suggest, the social benefits of openness in innovation are larger than the private benefits at the individual plant level, this suggests a potential role for public policy in promoting the spread of open innovation practices. In other words, the open innovation debate may move from analysis of firm strategy into the arena of public policy.

To date few, if any, public policy initiatives have focussed on promoting openness in innovation primarily because of the social benefits of openness. Instead, where open innovation initiatives have been undertaken they have focussed more directly on maximising the private returns to open innovation. Innovation intermediaries, for example, which provide network facilitation services, may aim to bridge gaps in networks and so facilitate knowledge exchange between partners as a way of promoting innovation (Yusuf, 2008).[12] Other open innovation initiatives – in both the public and private sectors – have seen open innovation as an enhanced commercialisation methodology, or a framework for the co-development of innovation. Centres such as IMEC or the Belgian Collective Research Centres typically combine in-house R&D activity with external collaborative relationships (Spithoven et al., 2011). Again, however, the emphasis is on maximising partners' returns to innovation rather than seeking to maximise any wider social benefits. Our results suggest, however, that in terms of both network facilitation and the co-development of innovation there would be significant positive social benefits from enhanced openness in addition to the acknowledged private benefits from increased innovation. While specific policy recommendations are beyond the remit of the present analysis, we would argue that failure to acknowledge these externalities of openness is likely to lead to a socially sub-optimal level of investment in promoting open innovation, an example of a 'policy failure'(Woolthuis et al., 2005). It also has to be recognised, however, that externalities of openness may provide incentives for firms to do less basic research in-house, especially where 'openness' is backed by public policy intervention. This may be a particular issue if there are erosion factors reducing the (private) returns to in-house R&D activity, suggesting that any public policy intervention in terms of open innovation would need to take into account the possible implications for incentives for private R&D, and indeed the implications for the public knowledge base which generates much of our basic research output.

As is the case with most instrumental-variable-based regression analyses, our results do need to be treated with some caution. Our identification of the effects of the externalities of openness relies on the following exclusion restriction. This assumes, first, that breadth (or number) of linkages at sector level in different Western European countries are determined by similar underlying causes, so that breadth of channels of knowledge sourcing/linkages in other Western European countries is a good predictor of breadth of knowledge linkages in Ireland. Second, we assume that the average sector-level breadth of linkages in other Western European countries affects the innovation performance of firms in Ireland only through our Irish spillover proxy, which is through the average breadth of linkages in the corresponding sector in Ireland. This seems a relatively sensible assumption, and we have tried to allow for other possible mechanisms, such as technological opportunity effects - but the assumption may nevertheless be too strong. Our results need not show the causal effects if the openness at sector-level elsewhere in Western Europe has a more direct effect on performance of firms in Ireland. Therefore, consideration of possible alternative instruments would be a welcome addition.

[12] Examples of organisations fulfilling this type of network facilitation role are KICs Cambridge (Acworth, 2008) and the Technology Advanced Metropolitan Area Association in Tokyo (Kodama, 2008).

In addition, because of the unbalanced nature of our dataset we cannot fully account for fixed effects at plant level. Therefore the estimated effects are not entirely within-plant effects and may perhaps be affected by unobserved heterogeneity at firm or sector level. There may be unobserved fixed characteristics of the sector or firm that affect both the extent of spillovers that a firm could absorb from its peers and the firm's innovation performance. These unobserved variables could induce correlation between the spillovers proxy and firms' innovation output, which is not fully due to spillover effects.

Finally, economists are often sceptical about the use of subjective questions in an econometric framework due to the measurement error and its correlation with large set of characteristics and behaviours of the business unit. For example, Bertrand and Mullainathan (2001) point out that the subjective data, as in our analysis, may be useful as explanatory variables, but the researcher must take care in interpreting the results since the estimated parameters may not show causal effects. However, our results in this paper point to a very robust evidence of positive association between our spillover proxy and innovation performance. Therefore given the potential (but not testable) validity of our key instrumental variable, and assuming that the limitations mentioned here are not crucial, the findings may indeed point to important causal effects.

Our analysis does suggest the value of carrying out further work on the externalities of openness. Future studies may find it useful to accompany subjective measures of the presence and importance of linkages with more detailed measurable and comparable information about the importance of different linkages. Identification of causal effects based on sudden exogenous changes in access to networks (for example, due to natural experiments) may yield stronger evidence for spillovers of openness in innovation. Also, it would pay to decompose the spillovers more explicitly into different clearly defined channels: an example here is Bloom et al. (2012) who use US patent data and divide knowledge externalities into the technology spillovers and competition effects. Further analysis of this type could make a useful contribution.

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Appendix A. Annex: Correlation table.

Source: IIP, 1994–2008.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
(1) Sales from new or improved products (%)	1.00																	
(2) Open innovation spillovers	0.15	1.00																
(3) Sector level average breadth of knowledge sources	0.11	0.55	1.00															
(4) Sector level average of importance of lack of partners as barrier to innovation (1–5)	0.03	0.34	0.43	1.00														
(5) R&D conducted in-house	0.39	0.16	0.12	0.04	1.00													
(6) Own breadth of linkages (0–8)	0.31	0.15	0.13	0.10	0.28	1.00												
(7) Employment (no.)	0.10	0.11	0.02	0.09	0.13	0.23	1.00											
(8) Establishment age (years)	−0.08	−0.02	0.01	−0.02	−0.02	0.01	0.13	1.00										
(9) Externally-owned	0.09	0.19	0.09	0.11	0.04	0.15	0.26	0.02	1.00									
(10) Workforce with degree (%)	0.18	0.19	0.25	0.16	0.16	0.14	0.08	0.00	0.14	1.00								
(11) Govt. support for product innovation	0.27	0.13	0.16	0.06	0.42	0.28	0.11	−0.01	0.00	0.15	1.00							
(12) Expected profits from innovating	−0.01	−0.04	−0.01	0.02	−0.06	0.00	−0.02	−0.02	−0.09	−0.08	−0.01	1.00						
(13) Herfindahl Index	−0.03	0.14	−0.13	0.00	0.00	0.03	0.03	0.14	−0.02	0.00	−0.03	0.00	1.00					
(14) Sector level R&D intensity	0.11	0.27	0.34	0.13	0.10	0.06	0.05	−0.05	0.11	0.14	0.16	−0.01	−0.27	1.00				
(15) 'High-tech' sector dummy	0.15	0.57	0.52	0.43	0.09	0.13	0.10	−0.14	0.23	0.24	0.14	−0.02	−0.33	0.41	1.00			
(16) FDI employment share (0–1) in the sector	0.02	−0.20	0.04	0.16	0.00	−0.02	0.00	0.03	−0.06	0.01	−0.02	0.03	0.04	−0.19	−0.16	1.00		
(17) Trade as a ratio to output	0.12	0.59	0.42	0.39	0.12	0.12	0.10	−0.06	0.23	0.20	0.10	−0.03	−0.17	0.19	0.75	−0.22	1.00	
(18) Export growth (%)	0.05	0.15	0.18	0.42	−0.02	0.04	0.09	−0.12	0.19	0.11	0.02	0.01	−0.19	0.01	0.51	0.18	0.35	1.00

Note: Correlations are constructed for the estimation sample.

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