EXPLORING THE LINK BETWEEN LOCAL AND GLOBAL KNOWLEDGE SPILLOVERS

Evidence from Plant-Level Data

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Abstract

We investigate the existence of local (within-country) and global (between-country) knowledge spillovers within a single analytical framework by considering specifically the role of agglomeration economies in fostering interactions between these two types of externalities. Our study is based on a database of Irish manufacturing foreign multinational and domestic plants covering the period 1990-1995. The results of our econometric analysis show that while the R&D undertaken by multinationals active in Ireland has had no significant impact on local plants' productivity, these multinationals have, nevertheless, through their presence favoured the diffusion of global R&D spillovers. Foreign affiliates in turn have directly gained from the size of the R&D stock in their origin country, but there is no evidence that foreign affiliates located in Ireland have benefited from local R&D spillovers. A fundamental difference between locally generated spillovers and locally transmitted global spillovers appears to be that the latter is much less constrained by distance decay effects.

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Section I: Introduction

Encouraging Research and Development activity (R&D) and the diffusion of the knowledge externalities it may create consistently remains an important strategic component of public policy across the globe. Importantly, the identification and quantification of any potential benefits derived from it is in practice not an easy task. In this regard, the literature on the economic effects of firms' Research and Development activities (R&D) does indeed strongly suggest the existence of R&D spillovers taking place locally within a given country, although subject to distance-decay effects; see, for instance, Jaffe 1986, Adam and Jaffe, 1996, and Orlando, 2004. At the same time there also appears to be evidence of R&D spillovers across countries as determined by the intensity of bilateral trade and international investment flows; see, for instance, Helpman and Coe, 1995, van Pottelsberghe de la Potterie and Lichtenberg, 2001, and Branstetter, 2006.[1] Despite the growing body of studies confirming both types of externalities, they are almost exclusively treated as two separate phenomena (see Keller, 2004 for a review of the literature). In the present paper we argue that such a dichotomy is largely artificial and may limit our understanding of and ability to measure the economic benefits related to R&D spillovers by not taking account of the potential interplay between them. More specifically, we introduce an empirical framework that allows for the transmission of knowledge through the spatial agglomeration of economic activities in terms of both intra-national and international channels and their interaction.

The analysis of our paper primarily relies on a framework distinguishing between foreign multinationals and local domestic firms and how these differ in terms of both local and global knowledge spillovers. In particular, while arguably both types of firms may benefit from locally generated knowledge, i.e., from what we call *local R&D spillovers*, they are likely to differ in terms of the access they have to knowledge generated outside of the country, labelled here *global R&D*

[1] In the remainder of the paper the terms knowledge spillovers and R&D spillovers will be used interchangeably, which, in both cases and following Griliches (1992) refer to the "the impact of discovered ideas or compounds on the productivity of the research endeavours of others" applied to the analysis of knowledge spillovers related to private businesses' R&D activities.

spillovers. In this regard, it seems reasonable to assume that multinationals can tap directly into the foreign knowledge pool of their home country. For example, Branstetter (2006) discovered that there are considerable transfer of knowledge between Japanese firms and their affiliates located in the US. In contrast to foreign multinationals, local firms instead should be more likely to reap benefits from foreign-sourced knowledge spillovers only indirectly via the extent to which their country or they themselves are linked to the global community, such as through trade, and/or through the foreign knowledge leaking from the local presence of foreign multinationals. [2] As support for the importance of the latter, one should note that Cassiman and Veugelers (2004) have, for instance, shown for a sample of firms based in Belgium that firms that source technology internationally generate local transfers more intensively, especially in the case of foreign affiliates. Thus through the co-existence of foreign multinationals and domestic firms we potentially have a setting where both types might benefit from locally generated knowledge subject to distance decay effects, but where for global knowledge spillovers only one group, namely domestic firms, may be relatively more exposed to the imperfect transmission of knowledge over space. It is within this context that the present study aims to show that it is important to take account of the interaction between local and global knowledge spillovers to be able to properly capture these externalities.

The extra layer of complexity added by considering both local and global spillovers simultaneously within our multinational versus domestic firm setting unsurprisingly requires very detailed information regarding plant-level nationality of ownership, R&D activities, productivity performance and geographical location in order to, in the words of Griliches (1992) "*detect the path of spillovers in the sand of the data*". In this regard we take advantage of a rich plant-level data for the Irish manufacturing industries spanning the time period 1990-1995 that allows us to characterize and spatially locate all R&D and multinational activity within Ireland.

[2] These arguments are indeed a transposition to the global vs local contexts of the notion of absorptive capability related to Research and Development (R&D) activities developed by Cohen and Levinthal (1990).

One should note that arguably the Irish case is particularly relevant to analyse the issues at stake here, since existing evidence suggests that an important reason for Ireland's extraordinary economic growth over the 1990s may have been that Irish domestic firms have greatly benefited from large knowledge spillovers derived from an increased foreign presence, despite the low level of R&D activity within Ireland.[3] For example, during the period covered here Irish total spending on R&D was 0.92 per cent of GDP compared to the EU15's 1.92 per cent, but its economic growth rate (measured by GDP growth rate) stood at 5.2% relative to the 1.8% of the latter during the period covered by our analysis.[4] The fact that Archarya and Keller (2007) find that Ireland has had an absorptive capacity of foreign knowledge spillovers from the US even higher than the UK or Canada then indeed suggests that local multinational presence may have played an important role in transmitting such global know-how that will in part have driven Ireland's economic success.

The econometric analysis here rests on estimating the determinants of plant-level productivity focusing on the role played by plants' own R&D, R&D performed by other plants in the same/different industries and spatial areas in Ireland and R&D performed abroad. We specifically address the issue of whether foreign multinationals' R&D activities in Ireland affect local plants' productivity level directly, through their on own level of R&D activity, and/or indirectly by channelling foreign R&D spillovers undertaken abroad (and specifically in their country of origin) and whether agglomeration of economic activities play a specific role in that respect. Given that our spatial allocation procedure for plant specific local R&D pools, following Duranton and Overman (2004), introduces some measurement error, our econometric estimation consists of an instrumental variables approach where we use as instruments other, arguably exogenous, location-specific variables. We find that domestic plants can benefit from R&D activity of other domestic plants

[3] A number of findings and features specific to Ireland may explain the apparent gap between its productivity performance and its still low own R&D activity. For instance, Van Pottelsberghe de la Potterie and Lichtenberg (2001) provide evidence showing that trade-embodied knowledge spillovers have been especially pronounced in Ireland compared to other OECD countries. Acharya and Keller (2007) argue that Ireland had a higher absorptive capacity of foreign knowledge spillovers.
[4] Sources: Eurostat and authors' calculations.

nearby, but that R&D undertaken by multinationals active in Ireland has had no significant impact on their productivity. Nevertheless local foreign multinationals have through their presence, favoured the diffusion of global R&D spillovers to their domestic counterparts. Foreign affiliates in turn, have directly gained from the size of the R&D stock in their origin country, but there is no evidence that foreign affiliates located in Ireland have benefited from local R&D spillovers. A fundamental difference between local generated spillovers and locally transmitted global spillovers appears to be that the latter is much less constrained by distance decay effects.

The rest of the paper is organised as follows, in Section II we provide more detailed account of the existing empirical literature dealing with local and global knowledge and of the relevance of the Irish case in such context and set out our analytical framework. Section III provides a description of the data used while Section IV describes our main econometric results. Section V concludes.

SECTION III: Data Description, Measurement of R&D Spillovers and Summary Statistics

A. Data Sources

Our plant level information come from three data databases collected by Forfás, the Irish policy and advisory board with responsibility for enterprise, trade, science, and technology in Ireland. The first is the Forfás employment survey which is an exhaustive annual plant level survey with information on the location, nationality of ownership,[5] sector of production, and yearly level of employment, and has been carried out since 1972. The second source is the Irish Economy Expenditure (IEE) Survey, an annual survey of larger plants in Irish manufacturing with at least 20-30 employees, with a coverage rate close to 80 per cent of the targeted plant population. This data set provides us with information on the level of output, value added, the level of employment, total wages, and the capital stock since 1990. The most important data for the purpose of the current

[5] Plants are identified as foreign if they have at least 50% foreign ownership. While arguably, plants with lower foreign ownership should possibly still be considered foreign owned, this is not necessarily a problem for the case of Ireland since almost all foreign direct investment in Ireland has been Greenfield investment rather than acquisition of local firms (see Barry and Bradley, 1997).

paper is the degree of R&D activity, measured as expenditure on R&D, of firms in Irish manufacturing. For this we are able to draw on Forfás' plant level Research and Development Surveys from 1986, 1988, 1990, 1991, 1993, and 1995, and Innovation Surveys spanning the periods 1990-1992 and 1994-1996, which collect information on R&D activity within Irish manufacturing. Importantly, these surveys are estimated by Forfás to cover all R&D active firms and thus can be argued to be exhaustive with regard to these seven years.

In terms of using these three data sources in conjunction with each other one should note that Forfás provides each plant with a unique numerical identifier, which allows one to link information across data sources and years. For our econometric analysis we use the employment data for identifying the population of plants in each of the relevant years and the R&D/Innovation surveys for identifying the subset of the population which are R&D active and the extent of their activity. The IEE then allows for a subset of these total factor productivity to be calculated.

We also use OECD data on R&D and bilateral trade between Ireland and its main OECD partners to construct measures of global R&D spillovers. The countries for which R&D data is available in the ANBERD database are Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the UK and the US. These nations also constitute the main origins of FDI in Irish manufacturing since they cover over 90% of total foreign employment in the industry. One should note that the OECD provides data on R&D activities by sector only at the ISIC 2 digit level, which results in 21 sectors for Ireland (listed in Table 1). Since we want to consider internationally as well as locally generated R&D spillovers simultaneously, we will use this sector classification throughout our analysis.

B. Calculation of Total Factor Productivity

Following Hall and Mairesse (1995), we base our empirical specification on a production-function framework and consider the link between R&D and plant-level productivity. An important issue in measuring plant level total factor productivity is how to deal with the endogeneity of input choices, including R&D. More precisely, if a plant can observe at least part of its total factor productivity early enough then it may choose to change its factor inputs, making direct estimates of productivity from regressing output on inputs biased. In a novel approach, Olley and Pakes (1996) use a structural model of firm dynamics to derive an estimation procedure that allows one to overcome this problem. This method provides robust estimation of the production function allowing for endogeneity of some of the inputs and controlling for unobserved quasi-fixed differences across plants. In the context of R&D, one problem with the Olley and Pakes (1996) procedure is, however, that investment in R&D may have an effect on the distribution of future productivity realizations. If this were the case, then not taking account of this could result in inconsistent estimates even under the Olley and Pakes (1996) procedure.[6] In this regard, Buettner (2003) has recently proposed an extension of the Olley and Pakes (1996) model incorporating R&D, and derived a revised estimation technique of total factor productivity. As Griffith et al (2007), we implement this extended approach to calculate our measures of total factor productivity.

C. Global R&D Stocks

In order to capture international R&D spillovers we consider R&D activities outside Ireland in terms of the OECD countries for which R&D data was available for the same sectors of activity and the time period we use. In this regard, we follow Coe and Helpman (1995) and the extension proposed by Lichtenberg and van Pottelsberghe de la Potterie (1998) who use trade data in order to obtain a weighted measure of R&D spillovers. These weights are given as follows:

$$w_{c,jt} = \frac{IMPORT_{c,jt}}{PROD_{IE,jt}} \qquad (1)$$

where $IMPORT_{c,jt}$ are import of Ireland in goods in sector *j* coming from country *c* at a given year *t*, and $PROD_{IE,jt}$ is the corresponding production level for this specific industry in Ireland. Using these weights we construct our measure of international R&D pool for a given sector *j* at a given year:

$$RD^{OECD} = \sum_{c} w_c \; RD_{ct} \qquad (2)$$

[6] One should note that this problem is also present in Levinsohn and Petrin's (2003) extension of the Olley and Pakes (1996) procedure.

where RD_{ct} is the R&D stock of country c at time t and is calculated as the cumulative sum since 1990, depreciated at a rate of 15 per cent. The variable RD^{OECD} measures therefore the foreign stock of R&D in the OECD and is intended to capture the R&D spillovers embodied in trade between Ireland and its main OECD partners. The idea behind using trade flow intensity as a weighting scheme is that foreign R&D stock will influence domestic productivity levels if trade is particularly intensive with Irish trade partners that are also R&D intensive. However, because such measures have been shown to be sensitive to potential bias,[7] we also experimented with using the geographical distance between Ireland and its OECD partners as a weighting scheme for international R&D spillovers in a way similar to Keller (2002). The results obtained in this case were fairly similar to those of our benchmark measure so that we only report the latter.

D. Local R&D Stocks

Previous studies of the role of local R&D spillovers used pre-defined spatially fairly aggregate administrative regions to determine geographical proximity; see, for instance, Orlando (2004). In this regard, our data provides us with information on the location of all plants in terms of geographical areas termed District Electoral Division (henceforth DEDs). Importantly, these DEDs are relatively small spatial units given that they have, on average, an area of 21 km^2 (standard deviation of 14 km^2), decomposing Ireland into 3440 spatial units - see Figure 1. A majority of these DEDs as they exist today were created in 1898 by the Local Government Act of Ireland, and hence their geographical breakdown can be seen as exogenous and should be expected to have little to no link with plants' location choices. The few exceptions in this regard are the DED breakdowns of the counties of Cork, Dublin, Galway, Limerick and Waterford, where population changes have prompted authorities to redefine the geographical breakdowns somewhat.

Of course, although these DEDs are fairly small spatial units, they generally encompass several plants and we unfortunately do not have the exact geographical location of these within their

[7] See Keller (1998).

DED. Faced with a similar problem previous studies, such as Orlando (2004) have simply assumed that all plants are located at the centre of their geographical region, thus biasing the geographical extent of spillovers towards zero. Here we instead follow the suggestion by Duranton and Overman (2004) and randomly allocate each plant to a unique coordinate within their DED. As noted by Duranton and Overman (2005), the error made on the location is of the same magnitude as the square root of the area of the smallest spatial unit. Using this generated exact coordinate we can then define plant-specific local areas *A* for which one can construct plant-specific local spillover measures.[8] One should note that this means that each plant will have its own specific geographic locality, although these may overlap depending on plants' relative location and the chosen size of the appropriate area *A*. We depict the location of our plants, after randomly allocating them within DEDs, across Ireland for 1995 in Figure 2. As can be seen, while there is some dispersion, there is also considerable agglomeration, particular around the major cities in Ireland (Cork, Dublin, Galway, and Limerick).

In order to construct our local R&D pool we consider an area *A* around each plant and sum all relevant R&D stocks within this area distinguishing between R&D performed within the same sector of activity and the R&D done in other sectors.[9] The relevant stocks are the cumulative value of R&D expenditure of existing plants since 1986 depreciated at a rate of 15 per cent. As a benchmark we construct four R&D spillover variables: $RD^{IE}_{SS,SA}$ is the total R&D pool in the same sector (*SS*) in the same area (*SA*) by other plants located in Ireland (*IE*), $RD^{IE}_{SS,OA}$ is the total R&D stock in the same sector but outside the area (*OA*), $RD^{IE}_{OS,SA}$ is the total R&D pool in other sectors of activity (*OS*) in the same area, while $RD^{IE}_{OS,OA}$, is the total R&D pool in other sectors of activity outside of the area – each measured as total R&D pool per square kilometre in 1995 values. Thus for each plant the sum

[8] In order to check the robustness of our results to the result of the random allocation process, we have also tried several different random allocations of plants within the DEDs and re-run our estimations. Results were very close to the ones reported here which should come as no surprise given the fairly small size of these geographical units, implying that the plants'-specific areas calculated through this random allocation process were not very different in each case.

[9] We follow Orlando (2004) who makes the distinction between intra and inter-sector R&D spillovers assuming that intra-sector R&D spillovers are likely to be more intensive.

of these four proxies constitutes the total R&D stock in Ireland – excluding its own R&D stock. We also experiment with decomposing our local R&D pools within Ireland into those generated by foreign and domestic plants. For instance, $RD_{SS,SA}^{IE,F}$ indicates the R&D pool generated by foreign affiliates in the same area and sector of activity and $RD_{SS,SA}^{IE,D}$ for domestic same sector, same area R&D stocks, respectively.

E. Descriptive Statistics

Combining all our data sets resulted in a sample of 1790 plants with 4308 observations for the period 1990 through 1995. Of these, 12 per cent were R&D active over our sample period, and 29 per cent were foreign affiliates. Table 1 provides some summary statistics of R&D activity and foreign presence by sector of activity for our sample. Despite the low R&D spending there is nevertheless considerable across sector heterogeneity in the degree of R&D activity, where this is highest in industries generally considered to be technology intensive, such as Motor Vehicles, Radio & TV, Chemicals and Rubber Plastics, as well as Electrical Machinery NEC.

Columns 2 and 3 of Table 1 provide the percentage of, respectively, total employment and total R&D due to foreign plants. Accordingly, foreign companies employ 35 per cent of the total workforce, but constitute nearly 70 per cent of all R&D activity. As a matter of fact in some sectors, such as the Tobacco, Chemicals, Rubber and Plastics, Medical and Precision instruments sectors, nearly all of R&D is undertaken by foreign affiliates. Nevertheless, there are some sectors, such as Food & Drinks, Pulp & Paper, Clothing and Basic Metals, where the percentage of R&D done by domestic plants is substantially higher than their foreign counterparts. One may want to note that these also tend to be the more low-technology intensive industries.

It is also of interest to examine the R&D intensity of domestic and foreign R&D active plants, where R&D intensity is measured as the R&D spending per employee. These figures are shown in Columns 4 and 5 of Table 1 and suggest that the R&D intensity of foreign plants is in general much higher than for domestic plants, except for sectors such as Computers and Office Machinery and Electrical Machinery nec.

Table 2 provides summary statistics concerning the productivity level of foreign and domestic plants, where we also distinguish within these categories between those that conduct R&D and those that did not over our sample period. Firstly, one may want to note that on average productivity levels of R&D-active plants are higher than those of non-R&D plants, independently of their nationality of ownership. The statistics also reveal that foreign plants that perform R&D have higher mean productivity levels compared to domestic ones.

SECTION IV: Econometric Analysis

A. Econometric Specification

The main focus of this paper is to measure the impact of R&D spillovers, both local and global, on plants' productivity. In this regard our benchmark equation to be estimated is similar to that in Griffith et al (2007) and given by:

$$TFP_{it} = \alpha + \beta_1 RD_{it}^{PLANT} + \beta_2 RD_{SS,SA\,it}^{IE} + \beta_3 RD_{SS,OA\,it}^{IE} + \beta_4 RD_{OS,SA\,it}^{IE} + \beta_5 RD_{OS,OA\,it}^{IE} + \beta_6 RD_{jt}^{OECD} + \lambda X_{it} + \mu_{it} \quad (3)$$

where TFP is total factor productivity, RD^{PLANT} is a plant's own R&D stock, $RD_{SS,SA}^{IE}, RD_{SS,OA}^{IE}$, $RD_{OS,SA}^{IE}$, and $RD_{OS,OA}^{IE}$ are the local spillovers variables as explained in Section III, RD^{INT} is the global (or international) spillover variable, $\boldsymbol{X}$ is a vector of other control variables, μ is an error term, and *i*, *j*, and *t* denote subscripts for plant, industry, and time varying variables. Definitions of all our variables used throughout our econometric analysis are given in Appendix .

An important aspect to consider in terms of the estimation of (3) is that μ should not contain any unobservable factors that may be correlated with our explanatory variables. One should note in this respect that *TFP* is, conditional on the appropriateness of the underlying structural model, by construction an unbiased estimator of total factor productivity and controls for unobserved quasi-fixed differences. Similarly, as noted by Griffith et al (2007), RD^{PLANT}, i.e., a plant's own R&D stock, can be argued to be exogenous. With regard to our local spillover proxies one should recall that these by construction exclude a plant's own R&D stock. Nevertheless, there may be other productivity enhancing, geographic factors that are the driving force behind location choices of plants and their decision to spend on R&D. In particular, the economic geography and regional growth literature has provided evidence on the role played by agglomeration economies on the location of innovative and R&D-intensive activities and on productivity levels; see Ciccone and Hall (1996) and Audretsch and Feldman (1996). In order to control for such agglomeration economies, we follow Ciccone and Hall (1996) and include as a control variable the employment density within the same area, $EDENSITY_{SA}$. We also take account of sector specific business cycles with the sectoral employment growth rate, denoted as SEGROWTH. Finally, we include year, sector, and county dummies to control for unobservable time specific, and time invariant sector county determinants of productivity, respectively.[10]

Another problem may arise given the fact that the exact locations of plants is only proxied by their random allocation within DEDs. This introduces measurement error into our geographically defined variables, and will tend to produce a downward (attenuation) bias in their estimated parameters. One way to take account of this is to instrument all geographically defined variables used in our analysis. Good candidates for plausible instruments in this regard are the local variables of other plants within the same DED. More precisely, since the local areas around plants within a DED are likely to overlap for at least some of them, they are at least partially correlated with each other. But a plant's productivity is unlikely to be directly determined by its nearby neighbours' local variables. To generate such instruments we hence, for each plant-year, calculate the average value of each location-specific variable for all other plants within the same DED. Additionally we use the

[10] Note that counties are different from the DEDs areas and cover much broader areas. Ireland is divided into 27 counties.

lagged values of a plant's own local variables as further instruments. For example, for our base specification in (3) this would include a total of 8 instruments – the lagged values of $RD^{IE}_{SS,SA}$, $RD^{IE}_{SS,OA}$, $RD^{IE}_{OS,SA}$, and $RD^{IE}_{OS,OA}$, as well, as the average values of these for all other plants within the same DED.

Another important issue in estimating (3) is that for some of the determinants of plant-level productivity we are examining the effect of more aggregated sectoral level variables on plant-level productivity. As shown by Moulton (1990), because standard errors are likely to be correlated for observations within more aggregated units their estimates may be biased downward. In order to take account of this we follow Bertrand et al (2003) and cluster error terms within NACE 2-digit sectors.

B. Base Specification Econometric Results

We start off by estimating (3) using two stages least squares (2SLS) for our total sample of plants for various specifications in Table 3. In the first column we initially ignore any local dimension of the R&D stock within Ireland and consider the area A around plants to simply be the whole of Ireland, so that $RD^{IE}_{SS,SA}$ and $RD^{IE}_{OS,SA}$ measure just the sum of the total stocks of R&D in the same and outside of the sector, respectively, of a plant and we thus do not need to include $RD^{IE}_{SS,OA}$ and $RD^{IE}_{OS,OA}$. As can be seen, a plant's own R&D stock has a positive and significant effect on its productivity. One also finds that the total R&D stock within the same sector increases a plant's productivity, while this is not the case for R&D done in other sectors. In other words, there are intra- but no inter-sectoral R&D spillovers. Our measure of the international stock of R&D has, however, no significant impact. The sectoral business cycles do not appear to affect plants' productivity.

In the remaining columns of Table 3 we then decompose both the within and outside of the sector R&D stocks into that located internal and that external of some pre-defined area, measured as a circle of a given radius around a plant, and instrument all our locally defined variables as discussed above. One may want to note that in all specifications, as in subsequent regression tables, the Sargan test statistic provides support for our choice of instruments. We first start off with a relatively small area, namely a 5km radius circle, the results of which are shown in the second column. As can be seen, from all our geographical variables, only $RD^{IE}_{SS,SA}$, i.e., the local R&D stock of plants operating in the same sector, is a significant determinant of productivity. This result implies that geographical distance matters in terms of benefiting from R&D spillovers, at least at a very short distance. It also indicates that it is important that the R&D is generated by plants belonging to the same sector of activity.

In columns 3 through 6 we then proceeded to enlarge the circle along pre-defined radiuses, namely 10, 20, 50, and 100km.[11] As can be seen, enlarging the circle to a 10 km radius provides qualitatively identical results to that of 5km. Moreover, the coefficient on $RD^{IE}_{SS,SA}$ increases by about 40 per cent, indicating that the full extent of spillovers from local R&D are not completely captured within a 5km radius circle. However, further increasing the size of the circle around plants not only substantially reduces the size of the coefficient, but also renders it insignificant – as is apparent from columns 4 through 6, where r was set at 20, 50, and 100 km, respectively. To verify that the cut-off point is indeed around 10km, we re-ran our specification, systematically enlarging area A by 1km radius increments and depict the estimated coefficients in Figure 4, where thicker portions of the line indicate statistically significance at at least the 5 % level. As can be seen, while the estimated effect varies somewhat, it is only significant within a 10km radius. These results thus strongly indicate that R&D spillovers are spatially bounded at a relatively short distance. In contrast, no matter what specification, we find no support for plants benefiting from international spillovers, at least as measured by RD^{INT}.

C. Foreign Multinational Plants

[11] One should note in this regard, that while we report only results for these, we also experimented extensively with radiuses that lie between the ones reported. However, these provided no additional information and thus, for space preservation sake, we do not report them.

One obvious problem with pooling all our data is that one is abstracting from the heterogeneities across plants, where these could potentially mean differences in the ability to benefit from R&D spillovers. For example, in Ireland it is well known that foreign multinationals constitute an important presence. However, foreign multinationals are generally assumed to be more technologically advanced than domestic; see Görg and Strobl (2001) and Görg and Greenaway (2004) for a review of the literature. They thus may have greater absorptive capacity to benefit from technological spillovers than their domestic counterparts and may, eventually, transmit new knowledge and technological improvements to the local economy via their activity and interactions with local companies.[12]

It must be noted, however, that in such economies like the Republic of Ireland, foreign multinationals are often suspected to mainly use the host country as a means of entering the European market, so that international R&D spillovers may be much more important than local ones if market access and trade is considered as an important channel for transmitting R&D spillovers. [13] Even if this were not the case, one would normally expect multinational firms to have substantial access to global knowledge pools given the spread of their plants across different countries; see Keller (2004). [14]

To further investigate the potentially different role of local and international R&D for foreign affiliates based in Ireland we re-estimated our base specification where the local area is defined by a 10 km radius in the first column of Table 4 for this sub-sample.[15] The results show that, while own R&D remains significant, there is, in contrast to the overall sample, no trace of local R&D spillovers. This lack of spillover effects continues to hold even when we enlarge the circle to anything greater than a radius of 10km, although we only report results for *r* equal to 20km. As argued above, this

[12] See Barrios et al. (2006) for an analysis of the local dimension of FDI-related spillovers in the Irish case.
[13] Indeed, on average, the largest proportion of total output of foreign multinational based in Ireland is for export purposes, see Barry and Bradley (1998) and Barrios et al. (2005).
[14] Indeed, this latter argument is similar to the one made in the case of plants belonging to the same firm but located in different places within the same country, although in that case it is often argued that there are distance decay effects; see, for instance, Adam and Jaffe (1996), Adam and Jaffe (1996) who call this the 'dilution' of R&D across multiple plants.
[15] We also experimented with the smaller radius of 5 km, but this also produced insignificant local effects.

may be in part because for foreign multinationals the international R&D stock may be much more important than the local one. However, as with the overall sample, the measure of international R&D pool, RD^{OECD} remains insignificant.[16]

One of the problems with the variable RD^{OECD} is, of course, that it only allows for trade as a channel to benefit from international R&D activity, while foreign multinationals may arguably have a much stronger direct link into the global technological community. We thus additionally proxied the total global technological knowledge pool available to a foreign plant with the total R&D stock within a sector in the OECD without using the trade-weighting scheme described in equation (1). As can be seen from the third column of Table 4, this variable similarly shows no significant impact on productivity. Since the US is often argued to be the technological leader in many manufacturing sectors we further experimented with only using the US stock of R&D within the same sector as a measure of potential spillovers, see Griffith et al. (2007). Again, however, this alternative measure, shown in the fourth column, remains insignificant.

One could also argue that multinationals may be much more likely to be able to tap into the technological pool of their origin country rather than that of the global community. To proxy for this we thus alternatively used only the R&D stocks within the same sector of the origin country as potentially spillover creating, the results of the inclusion of this are shown in the fifth column of Table 4. Supportive of our proposition, the origin country specific measure displays a significant positive coefficient, thus suggesting that foreign multinationals do actually benefit from spillovers from R&D activity generated within their sector in their origin country.

One concern about the significance found on the proxy constructed from the origin stocks is that, as argued by Keller (1998), one may be capturing other-than-FDI related R&D spillovers. As a robustness check Keller (1998) suggest to randomly allocate bilateral trade flows and we here use a similar approach in our measure by reassigning OECD countries' R&D stock by sector across

[16] The only other significant control variable in Table 4 is local employment density, however, only when the local area is defined as 20km.

countries using a randomised allocation procedure for each sector. Reassuringly, our results from the final column of Table 4, where the coefficient is now insignificant, however, suggest that the R&D pool stemming form the country of origin of foreign affiliates located in Ireland does indeed positively influence their productivity level.

D. Domestic Plants

Our arguments for why multinationals may differ in their ability to benefit from R&D spillovers of course also provide justification for separately examining domestic plants and we do so in Table 5. First of all one should note that, as for foreign plants, local plants' own R&D stock significantly increases their productivity. In contrast, international R&D as measured by RD^{OECD} is not a significant determinant. In this regard, we also experimented with using the total OECD R&D stock without the trade-weighting scheme, but similarly the coefficient was insignificant.

In terms of our measure of local spillovers, we find for domestic plants that the R&D stock of plants operating in the same sector within a 10 km radius has positive effects on productivity, although somewhat smaller than for the overall sample. Increasing the local area to any greater radius makes these spillover effects vanish, however - although we only report results for *r* equal to 20km. Thus, local spillovers are shown here again to take place within a fairly narrow geographic scope. This also suggests that the general results found in Table 3 when considering all plants (i.e., domestic and foreign plants together) was in fact driven by the domestic rather than foreign plants in the sample. Another potentially interesting finding is that in the first column of Table 5, where the local area of reference is defined by a circle of a 10km radius around a given plant, the coefficient on $RD^{IE}_{OS,SA1}$ is significantly negative – in other words, local R&D activity by plants in other sectors reduces productivity. A possible reason for this may be that greater local R&D activity puts a strain on local inputs, such as skilled labour. One may want to note in this regard, that once one considers these two countervailing forces, the overall net effect is close to zero, indicated by the relative size of the coefficients of these two variables. Finally, we also find that local employment density, possibly through agglomeration economies, also positively affects plant productivity.

As suggested by the FDI literature, many domestic plants simply may not have the absorptive capacity to benefit from R&D done by neighbouring foreign multinationals. In contrast, they are arguably more likely to benefit from innovative activity of similar domestic plants. To investigate this we calculated the local R&D stocks for foreign and domestic plants separately, as shown in the third column of Table 5, where these are indicated by "F" and "D" subscripts.[17] Our results of this exercise displayed in Column 3 of Table 5 show that while the same sector/same area foreign R&D stock ($RD^{IE,F}_{SS,SA1}$) is insignificant, the coefficient on the domestic counterpart ($RD^{IE,D}_{SS,SA1}$) not only is significant, but also is 8 per cent larger than for the total R&D stock measure. However, again the negative spillovers from innovative activity of other domestic plants in other sectors nets out any benefits from same sector local R&D activity. Also, further increasing the size of the local area to a 20km radius again renders any local domestic R&D spillovers insignificant, thus indicating that the scope for geographical spillovers takes place within a relatively small distance.

It is important to note that in Ireland many domestic plants act as intermediate suppliers to foreign multinationals, and that such a direct link may feasibly make distance less relevant for R&D spillovers. We thus increased the spatial scope of the area for which spillovers from local FDI may take place, while holding the scope of domestic spillovers to occur within a 10km radius. In addition to redefining the other local foreign controls accordingly, we also extended our measure of local employment density to encompass this greater locality. The results shown in columns (5) and (6) of Table 5 for areas of both 20 and 50 km (as well as using other non-reported larger radiuses) suggest that different geographical scopes by nationality are not likely to be the cause behind the lack of spillovers from foreign R&D.

[17] In order to simplify the readability of our results, we only report estimates when decomposing the R&D spillovers for the same sector into its domestic and foreign component, we also experimented with decomposing the outside the sector R&D stocks by nationality, but this did not alter our findings.

E. Domestic Plants and International R&D Spillovers

As discussed earlier, by definition multinational plants are part of a greater multi-plant corporation, where the headquarters and, potentially, other affiliates are located outside of Ireland. Thus, R&D activity in Ireland may only be a small part of total R&D expenditure by the entire operation of a given multinational and hence a poor proxy of the total local foreign pool of innovative knowledge that domestic plants can potentially tap into. In this regard, one would ideally like to know how much R&D is done within the entire global operation for all foreign affiliates located in Ireland – information that is, unsurprisingly, not available to us. Instead we use as a proxy for the total local knowledge available from foreign plants the total R&D stock within the same sector in the origin country of the foreign plant. One may want to note that the results from our foreign plant sample provided some evidence that this may not be an unreasonable proxy of the knowledge pool that a foreign affiliate in Ireland has access to.

To arrive at a measure of the total potential local foreign knowledge pool for each plant we weight and sum the OECD R&D stocks by the relative share of total foreign employment of the relevant foreign plants within the same geographical area and the same sector of activity. Omitting, for convenience sake, the sector of activity subscript, the measure of R&D pool is therefore:

$$RD_{SS,SA}^{OECD} = \sum_{c} \alpha_{c,A} RD_{c} \qquad (5)$$

where $\alpha_{c,A} = \frac{EMP_{c,A}}{EMP_{A}}$

and $\alpha_{C,A}$ is the share of employment in a geographic area *A* by multinationals from a country *c* for a given sector of activity *j* and where $EMP_{c,A}$ and EMP_A are the employment level of all multinationals from country *c* in area *A* and the level of total employment in area *A* respectively. We analogously also created a measure for the R&D pool outside the area *A*, $RD_{SS,OA}^{OECD}$. As before, given that the geographical areas considered are plant-specific and based on distance measured between each pair of plant, these variables are uniquely defined for each plant considered.[18]

The results of including $RD_{SS,SA}^{OECD}$ and $RD_{SS,OA}^{OECD}$ where the local area is defined as falling within a 10km radius are shown in the first column of Table 6. As can be seen, there is no evidence of any spillovers arising from access to the foreign pool of R&D via the presence of local foreign affiliates. In line with our previous argument, we also allowed for a greater geographic scope of foreign R&D spillovers for domestic plants by systematically increasing this radius for columns (2) through (6), while holding the size of domestic locality constant.[19] Accordingly, while there is still no sign of productivity benefits arising from being 'close' to innovative foreign multinationals when one moves from 10 to 20 and then to 50 km, once the circle around each plant is enlarged to 100km, one finds a positive and significant coefficient on our variable of interest, $RD_{SS,SA2}^{OECD}$. Further enlarging *A2* to 200km and then 300km radius means further increasing the value of the coefficient on $RD_{SS,SA2}^{OECD}$ from 0.006 to 0.206, while remaining significant. This thus suggests that once one allows for the possibility of access to the knowledge pool of the origin country via local foreign presence and a substantially greater geographic scope than for domestically produced R&D stock, domestic plants can indeed benefit from R&D spillovers arising from local multinationals. As a matter of fact, when we consider the geographical scope to include the entire country, as shown in the last column of Table 6, the coefficient not only remains significant but portrays its highest value. This suggests that, unlike benefits arising from domestic R&D, R&D spillovers emanating from foreign multinationals to domestic plants are not geographically limited, at least within Ireland.

[18] Note that, in order to keep the presentation of our results short we have omitted here the inclusion of the same variables as defined in (5) but for other sectors of activity. The results presented here are similar enough such that we preferred reporting only those including the $RD_{SS,SA}^{OECD}$ and $RD_{SS,SA}^{OECD}$ variables.

[19] In order to distinguish these areas, the area concerning the domestic R&D pool is numbered A1 and the area for the foreign R&D pool is numbered A2.

F. Exclusion of Potentially Endogenous DEDs

As noted in the data description section, while most DEDs were created at the end of the 19th century, there were some boundary changes in counties that experienced considerable population growth recently. Arguably, these may then not be exogenous with regard to plant location. In order to indirectly address this we re-ran all our estimations excluding the relevant counties, namely counties Cork, Dublin, Galway, Limerick and Waterford as a robustness check. We report the re-estimation of our main results from the total sample(s) for the same area / same sector spillover measures in Table 7.[20] As can be seen for the total sample, qualitatively and quantitatively the finding that spillovers from within the same sector R&D activity are productivity enhancing is fairly similar. Similarly, for the domestic and foreign sub-sample results of Tables 4 and 5, excluding the aforementioned DEDs produces similar qualitative results, although with some quantitative differences. The main difference for the non DED changing subsample can be found in investigating the role of international R&D spillovers through local foreign multinational presence. More specifically, unlike the overall sample, such spillovers start at 100km and disappear again if one considers a local area to be within 200km. One should note that one reason for this contrasting finding may be that a large portion of foreign multinationals are located in the excluded counties. Nevertheless, a general conclusion of this sub-sample does suggest that the R&D stock of foreign multinationals should be defined solely on grounds of their local R&D expenditures and that any spillovers arising from such plants are likely to suffer from less of a distance decay effect than those coming from other domestic plants' innovative activity.

Section V: Concluding remarks

In this paper we link local and global R&D spillovers and analyse their impact on plants' productivity using the case study of Ireland. Our paper provides a number of contributions to the existing literature on R&D-related spillovers. For one, we believe it to be the first to test the

[20] We have also re-estimated tables 4 and 5 for this sub-sample; see Tables 4B and 5B in the Appendix.

simultaneous existence and relative importance of both local and global R&D spillovers in the context of productivity analysis at the plant level. Secondly, while a possible interplay between the two types of externalities have been left untouched by existing empirical studies, our paper shows that these interactions do exist and provide new insights that can enhance our understanding of knowledge flows and their impact on productivity differentials.

Our econometric analysis suggests that domestic plants can benefit from local R&D activity of other domestic plants. While R&D undertaken by foreign multinationals active in Ireland has had no significant impact on domestic plant productivity, the presence of foreign multinationals can induce the diffusion of global R&D spillovers to these. Foreign affiliates, in contrast, do not seem to have gained from R&D activity within Ireland, but do reap benefits from the size of the R&D stock in their origin country. A fundamental difference between local generated spillovers and locally transmitted global spillovers appears to be that the latter is much less constrained by distance decay effects.

More generally, our findings indicate in particular that the transmission of global knowledge spillovers is likely to be more subtle than purely local knowledge spillovers and depend on the exposure to global innovation and the existence of channels allowing firms to tap into the global knowledge pool. In other words, multinationals' presence can represent an important channel for transmitting such global knowledge spillovers, independently of their technological and R&D activity in the local market.

Table 1: Summary Statistics

Sector	(1) R&D plants (% of total)	(2) Empl. of For. plants (% of total)	(3) R&D of For. plants (% of total)	(4) R&D intensity Dom. plants	(5) R&D intensity For. plants
Food Pr. & Drinks	0.08	0.27	0.24	0.29	0.32
Tobacco Pr.	0.10	0.84	1.00	0.00	0.11
Textiles	0.11	0.39	0.59	0.24	0.18
Clothing	0.11	0.21	0.06	0.13	0.09
Wood Pr. & Cork	0.04	0.28	0.57	0.08	0.21
Pulp, Paper, etc.	0.12	0.17	0.10	0.38	0.13
Publish., Printing	0.06	0.07	0.14	0.07	0.43
Chemicals	0.22	0.36	0.83	0.44	2.94
Rubber & Plastic	0.22	0.38	0.88	0.51	2.84
O. Non-Met. Mi.	0.05	0.11	0.12	0.13	0.32
Basic Metals	0.15	0.39	0.04	0.27	0.14
Fabricated Metal	0.06	0.15	0.26	0.09	0.88
Mach. & Equ. nec	0.11	0.22	0.41	0.58	1.01
Comp. & Off. M.	0.17	0.80	0.64	0.94	0.94
Elect. Mach. nec	0.20	0.60	0.48	1.49	0.71
Radio, TV, etc.	0.36	0.70	0.68	0.90	1.01
Med.& Prec. Instr., etc.	0.19	0.81	0.80	0.87	3.05
Motor Vehicles	0.31	0.57	0.76	1.38	3.23
O. Transp. Equ.	0.09	0.38	0.32	0.34	0.54
TOTAL*	0.12	0.35	0.69	0.32	1.36

(1) % of plants doing R&D
(2) % of employment in foreign-owned companies
(3) % of R&D in the sector done by foreign companies
(4) R&D spending per employee in thousands euros (1986 prices)
(5) R&D spending per employee in thousands euros (1986 prices)unweighted mean values

Table 2: TFP Measure

	All		R&D		Non-R&D	
	Mean	***St. Dev.***	**Mean**	***St. Dev.***	**Mean**	***St. Dev.***
Total	9.6	*1.9*	10.1	*1.9*	9.4	*1.9*
Foreign	10.9	*2.0*	11.3	*1.9*	10.7	*2.0*
Domestic	9.0	*1.6*	9.2	*1.3*	9.0	*1.7*

Table 3: All Plants

	(1)	(2)	(3)	(4)	(5)	(6)
RD^{PLANT}	0.021**	0.022**	0.021**	0.020**	0.020**	0.020**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{SS,SA}$	0.011**	0.016**	0.020**	0.009	0.001	0.002
	(0.000)	(0.008)	(0.005)	(0.143)	(0.713)	(0.715)
$RD^{IE}_{SS,OA}$	0.000	0.016	0.010	0.005	0.001	0.021
	(0.912)	(0.339)	(0.536)	(0.670)	(0.942)	(0.360)
$RD^{IE}_{OS,SA}$		-0.018	-0.007	-0.009	-0.003	-0.002
		(0.430)	(0.641)	(0.372)	(0.772)	(0.846)
$RD^{IE}_{OS,OA}$		-0.212	0.129	-0.134	-0.014	-0.002
		(0.550)	(0.515)	(0.334)	(0.861)	(0.967)
$EDENSITY_{SA}$		-0.538	-0.527	-0.733	3.366	4.602
		(0.279)	(0.632)	(0.698)	(0.135)	(0.639)
RD^{OECD}	-0.009	-0.004	-0.011	-0.007	-0.011	-0.009
	(0.606)	(0.831)	(0.546)	(0.780)	(0.425)	(0.601)
SEGROWTH	0.117**	0.155*	0.124*	0.130	0.115*	0.122*
	(0.007)	(0.015)	(0.027)	(0.087)	(0.025)	(0.021)
A:	*All*	*5km*	*10km*	*20km*	*50km*	*100km*
Obs.	4308	4308	4308	4308	4308	4308
Plants	1790	1790	1790	1790	1790	1790
Hansen stat.		4.600	3.126	5.868	7.405	8.722
Hansen p-value		0.204	0.373	0.118	0.192	0.121
R-SQ	0.052	0.010	0.047	0.044	0.048	0.049

Notes: (1) Boostrapped p-values in parentheses. (2) Estimated coefficients on constant term, time (year) dummies, and sector (Nace 2 digit) dummies not reported. (3) A: Size of Area; PLANT: own plant R&D; IE: R&D performed in Ireland. SS: same Nace 2-digit sector; OS: outside Nace 2-digit sector; SA: same area; OA: outside area; EDENSITY: employment density; (4) ** and * signify statistical significance at the 1 and 5 per cent levels, respectively.

Table 4: Foreign Plants

	(1)	(2)	(3)	(4)	(5)	(6)
RD^{PLANT}	0.017**	0.018**	0.017**	0.017**	0.017**	0.017**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{SS,SA}$	0.009	-0.001	0.009	0.009	0.010	0.009
	(0.210)	(0.921)	(0.201)	(0.211)	(0.194)	(0.209)
$RD^{IE}_{SS,OA}$	0.011	0.002	0.011	0.011	0.009	0.011
	(0.195)	(0.714)	(0.201)	(0.200)	(0.280)	(0.199)
$RD^{IE}_{OS,SA}$	-0.001	-0.012	-0.001	-0.003	-0.000	-0.002
	(0.939)	(0.501)	(0.938)	(0.874)	(0.988)	(0.931)
$RD^{IE}_{OS,OA}$	0.252	-0.005	0.251	0.259	0.240	0.252
	(0.231)	(0.972)	(0.231)	(0.210)	(0.285)	(0.229)
$EDENSITY_{SA}$	0.264	1.589**	0.268	0.274	0.240	0.268
	(0.442)	(0.009)	(0.438)	(0.428)	(0.477)	(0.437)
SEGROWTH	0.196	0.205	0.173	0.155	0.192	0.198
	(0.118)	(0.065)	(0.127)	(0.147)	(0.115)	(0.107)
RD^{OECD}	0.009	0.013	-0.078	-0.104	0.019**	0.000
	(0.803)	(0.638)	(0.628)	(0.274)	(0.003)	(0.832)
A:	*10km*	*20km*	*10km*	*10km*	*10km*	*10km*
INT:	*PL*	*PL*	*OECD*[§]	*US*	*ORIGIN*	*Random*
Obs.	1250	1250	1250	1250	1250	1250
Plants	520	520	520	520	520	520
Hansen stat.	7.862	2.919	7.972	8.049	7.145	7.966
Hansen p-value	0.164	0.712	0.158	0.154	0.210	0.158
R-SQ	0.102	0.093	0.102	0.102	0.121	0.102

Notes: (1) Boostrapped p-values in parentheses. (2) Estimated coefficients on constant term, time (year) dummies, and sector (Nace 2 digit) dummies not reported. (3) A: Size of Area; PLANT: own plant R&D; IE: R&D performed in Ireland. SS: same Nace 2-digit sector; OS: outside Nace 2-digit sector; SA: same area; OA: outside area; EDENSITY: employment density; (4) ** and * signify statistical significance at the 1 and 5 per cent levels, respectively.

[§] simple sum of R&D in OECD countries by sector, without considering the weighted scheme described in equation (8)

Table 5: Domestic Plants and Local R&D by Nationality of Ownership

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RD^{PLANT}	0.013**	0.013**	0.013**	0.012**	0.013**	0.015**	0.014**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{SS,SA1}$	0.013*	0.003					
	(0.049)	(0.704)					
$RD^{IE}_{SS,OA1}$	-0.002	-0.001					
	(0.893)	(0.917)					
$RD^{IE}_{OS,SA1}$	-0.015**	-0.011	-0.014*	1.743	-0.006	-0.009	-0.006
	(0.003)	(0.146)	(0.011)	(0.198)	(0.267)	(0.164)	(0.329)
$RD^{IE}_{OS,OA1}$	0.187	-0.021	0.223	0.154	0.205	-0.168	-0.072
	(0.137)	(0.860)	(0.399)	(0.535)	(0.352)	(0.619)	(0.782)
$RD^{IE,D}_{SS,SA1}$			0.014*	0.001	0.016*	0.020*	0.020*
			(0.048)	(0.902)	(0.035)	(0.030)	(0.020)
$RD^{IE,D}_{SS,OA1}$			0.004	0.014	0.001	0.045	0.068
			(0.860)	(0.388)	(0.964)	(0.311)	(0.196)
$RD^{IE,F}_{SS,SA2}$			-0.005	-0.012	-0.011*	0.003	-0.003
			(0.327)	(0.060)	(0.028)	(0.708)	(0.765)
$RD^{IE,F}_{SS,OA2}$			0.008	0.030	0.008	-0.043	-0.039
			(0.327)	(0.290)	(0.181)	(0.160)	(0.066)
$EDENSITY_{SA}$	0.646*	1.012	0.721*	-0.010	1.046	5.622	11.120
	(0.034)	(0.436)	(0.028)	(0.261)	(0.242)	(0.054)	(0.106)
RD^{OECD}	-0.034	-0.029	-0.047	-0.088	-0.057	0.109	0.097
	(0.144)	(0.176)	(0.186)	(0.284)	(0.155)	(0.428)	(0.465)
SEGROWTH	0.081	0.089	0.118	0.249	0.133	-0.614	-0.580
	(0.086)	(0.117)	(0.409)	(0.505)	(0.351)	(0.244)	(0.215)
A1:	*10km*	*20km*	*10km*	*20km*	*10km*	*10km*	*10km*
A2:			*10km*	*20km*	*20km*	*50km*	*100km*
Obs.	3058	3058	3058	3058	3058	3058	3058
Plants	1270	1270	1270	1270	1270	1270	1270
Hansen stat.	6.353	4.349	7.966	5.565	5.622	3.296	5.633
Hansen p-value	0.273	0.500	0.241	0.351	0.467	0.510	0.228
R-SQ	0.17	0.17	0.17	0.18	0.18	0.19	0.25

Notes: (1) Boostrapped p-values in parentheses. (2) Estimated coefficients on constant term, time (year) dummies, and sector (Nace 2 digit) dummies not reported. (3) A: Size of Area; PLANT: own plant R&D; IE: R&D performed in Ireland. SS: same Nace 2-digit sector; OS: outside Nace 2-digit sector; SA: same area; OA: outside area; EDENSITY: employment density; (4) ** and * signify statistical significance at the 1 and 5 per cent levels, respectively.

Table 6: Domestic Plants and Foreign Presence as Transmitter of Foreign R&D

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RD^{PLANT}	0.013**	0.013**	0.013**	0.013**	0.013**	0.013**	0.013**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{OS,SA1}$	-0.014**	-0.007	-0.005	-0.005	-0.004	-0.004	-0.004
	(0.007)	(0.183)	(0.292)	(0.402)	(0.397)	(0.390)	(0.452)
$RD^{IE}_{OS,OA1}$	0.320	0.201	0.150	0.131	0.096	0.088	0.124
	(0.167)	(0.286)	(0.395)	(0.482)	(0.592)	(0.647)	(0.542)
$RD^{IE,D}_{SS,SA1}$	0.016*	0.016*	0.015*	0.014*	0.015*	0.015*	0.015*
	(0.044)	(0.032)	(0.031)	(0.011)	(0.044)	(0.043)	(0.047)
$RD^{IE,D}_{SS,OA1}$	0.035	-0.008	-0.008	-0.010	-0.005	-0.007	-0.008
	(0.324)	(0.670)	(0.662)	(0.646)	(0.777)	(0.664)	(0.627)
$RD^{OECD}_{SS,SA2}$	-0.000	0.001	0.003	0.006*	0.040*	0.206*	0.240*
	(0.794)	(0.492)	(0.082)	(0.044)	(0.048)	(0.036)	(0.030)
$RD^{OECD}_{SS,OA2}$	-0.019	0.030	0.013	0.001	-0.001	0.001	
	(0.106)	(0.351)	(0.504)	(0.903)	(0.545)	(0.694)	
$EDENSITY_{SA1}$	0.782*	0.743	5.383*	13.394*	35.661	-37.752	-6.493
	(0.039)	(0.424)	(0.043)	(0.015)	(0.054)	(0.670)	(0.930)
RD^{OECD}	0.023	-0.066	-0.052	-0.040	-0.060	-0.165	-0.190
	(0.740)	(0.065)	(0.087)	(0.261)	(0.104)	(0.069)	(0.082)
SEGROWTH	-0.144	0.178	0.170	0.156	0.155	0.345	0.410
	(0.607)	(0.162)	(0.193)	(0.269)	(0.221)	(0.191)	(0.162)
A1:	*10km*	*10km*	*10km*	*10km*	*10km*	*10km*	*10km*
A2:	*10km*	*20km*	*50km*	*100km*	*200km*	*300km*	*All*
Obs.	3058	3058	3058	3058	3058	3058	3058
Plants	1270	1270	1270	1270	1270	1270	1270
Hansen stat.	11.006	7.128	7.139	9.983	10.991	9.788	10.058
Hansen p-value	0.088	0.416	0.415	0.190	0.139	0.201	0.122
R-SQ	0.17	0.18	0.19	0.19	0.19	0.18	

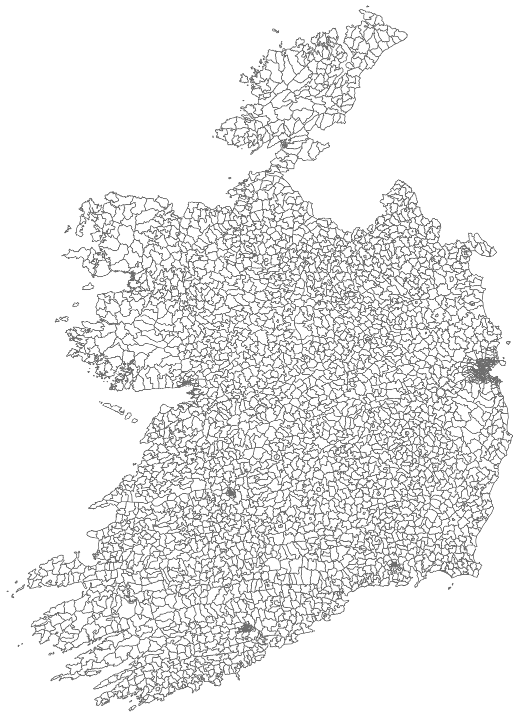
Notes: (1) Boostrapped p-values in parentheses. (2) Estimated coefficients on constant term, time (year) dummies, and sector (Nace 2 digit) dummies not reported. (3) A: Size of Area; PLANT: own plant R&D; IE: R&D performed in Ireland. SS: same Nace 2-digit sector; OS: outside Nace 2-digit sector; SA: same area; OA: outside area; EDENSITY: employment density; (4) ** and * signify statistical significance at the 1 and 5 per cent levels, respectively.

Table 7: Summary of Results - Non DED Changing Sample

	(1)	(2)	(3)	(4)	(5)	(6)
RD^{PLANT}	0.019**	0.017**	0.016**	0.016**	0.015**	0.016**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{SS,SA}$	0.023**	0.006				
	(0.000)	(0.398)				
$RD^{IE,D}_{SS,SA1}$			0.028**	0.031**	0.027**	0.030**
			(0.002)	(0.002)	(0.006)	(0.002)
$RD^{IE,F}_{SS,SA2}$			0.018			
			(0.070)			
$RD^{OECD}_{SS,SA2}$				0.018*	0.111	0.109
				(0.030)	(0.265)	(0.338)
RD^{OECD}	0.003	0.031**	-0.039			
	(0.911)	(0.000)	(0.578)			
Replication of:	*T:3, C:3*	*T:4, C:5*	*T:5, C:3*	*T:6, C:5*	*T:6, C:6*	*T:6, C:7*
Obs.	2066	597	1469	1469	1469	1469
Plants	945	276	699	699	699	699
Hansen stat.	2.821	5.466	6.333	6.038	9.663	9.175
Hansen p-value	0.588	0.362	0.387	0.535	0.208	0.164
R-SQ	0.043	0.119	0.033	0.033	0.018	0.009

Notes: (1) Boostrapped p-values in parentheses. (2) Estimated coefficients on constant term, time (year) dummies, and sector (Nace 2 digit) dummies not reported. (3) A: Size of Area; PLANT: own plant R&D; IE: R&D performed in Ireland. SS: same Nace 2-digit sector; OS: outside Nace 2-digit sector; SA: same area; OA: outside area; EDENSITY: employment density; (4) ** and * signify statistical significance at the 1 and 5 per cent levels, respectively.

Figure 1: Breakdown of Ireland into District Electoral Division (DEDs)



Source: Census of Ireland, http://www.cso.ie/census/SAPs.htm 2006 census: small area population statistics (SAPS)

Figure 2: Location of All Plants (1995)

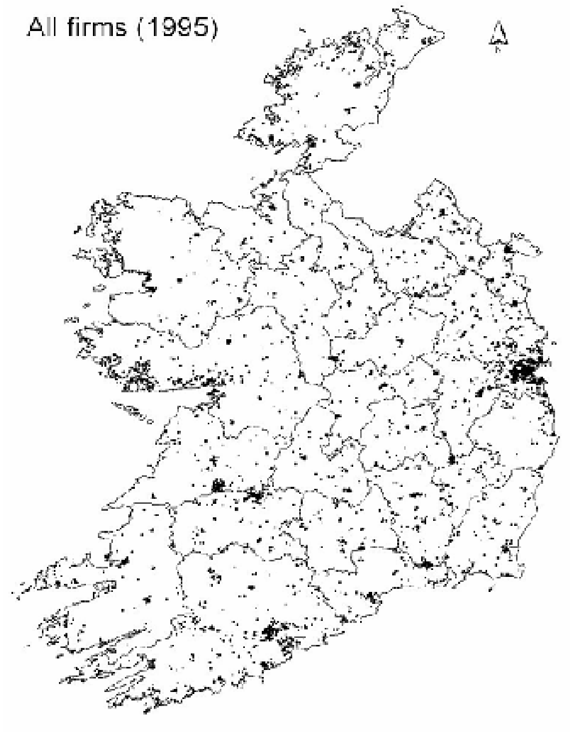


Figure 3: Location of Plants doing R&D (1995)

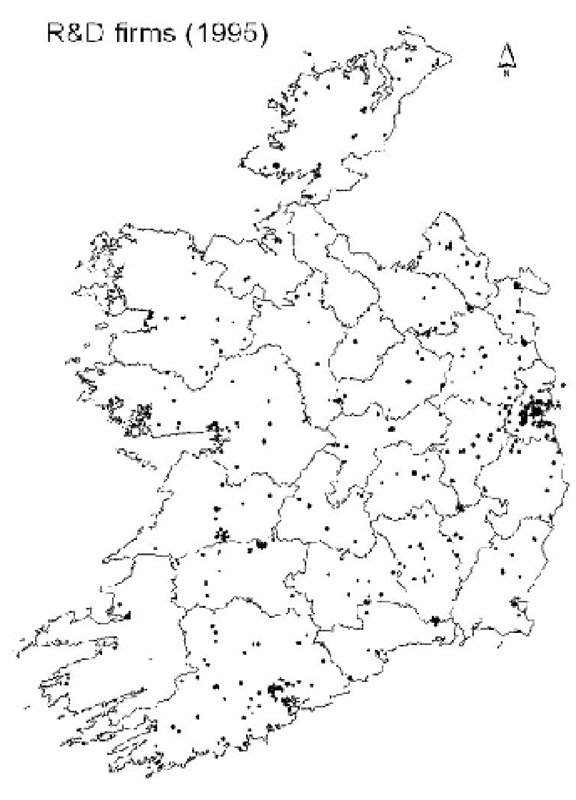
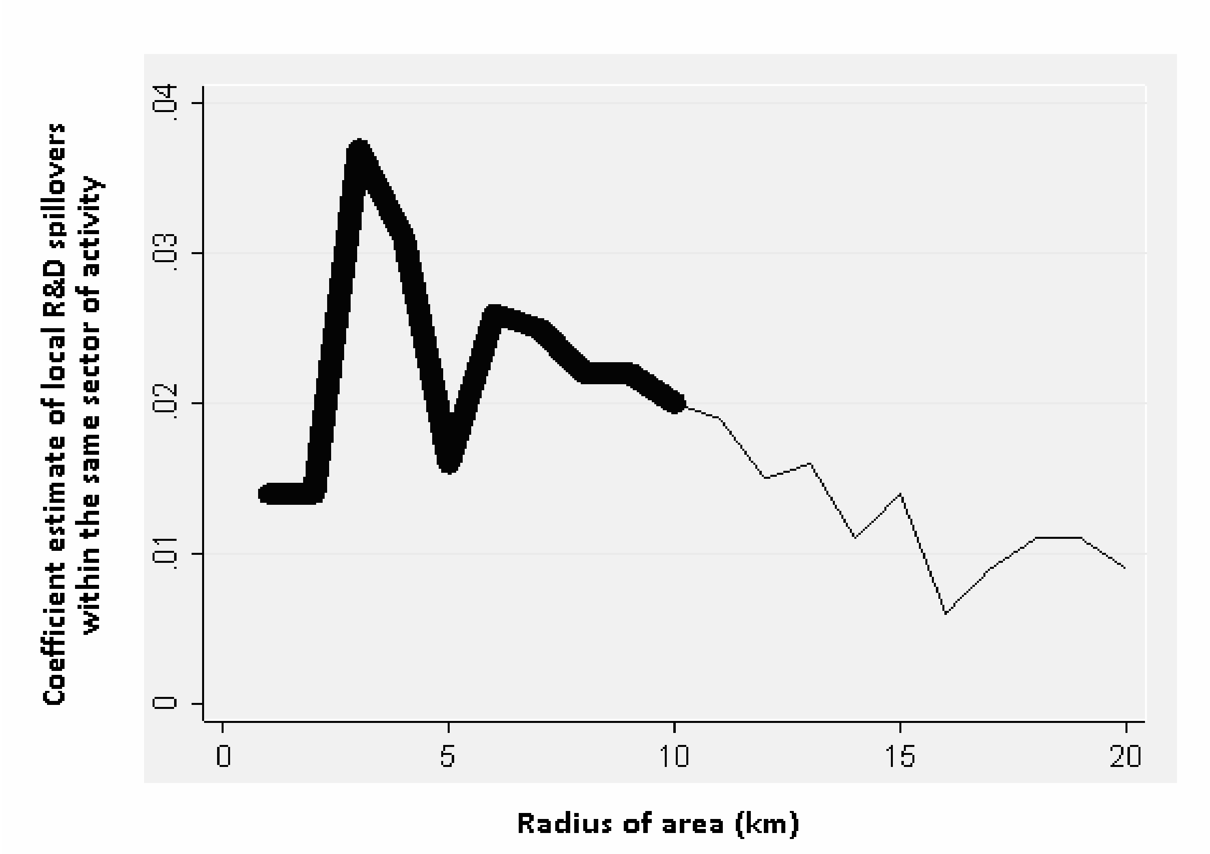


Figure 4: The distance decay effect on R&D spillovers



Notes: Results based on estimation of equation (3). Results of successive estimations obtained by enlarging area A by 1 km successive increments, from 1 to 20 km. Thick line corresponds to coefficient estimates significant at 5% confidence level. Thin line correspond to insignificant coefficients.

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Appendix A: Variable Definitions

Superscripts = origin of RD stock

Subscripts = spatial and sectoral-scope of RD stock

Variable	Definition
RD^{PLANT}	Plant's own R&D stock
$RD^{IE}_{SS,SA}$	R&D stock pool performed in Ireland, within same sector within area A
$RD^{IE}_{SS,OA}$	R&D stock pool performed in Ireland, within same sector outside area A
$RD^{IE}_{OS,SA}$	R&D stock pool performed in Ireland, outside sector within area A
$RD^{IE}_{OS,OA}$	R&D stock pool performed in Ireland, outside sector outside area A
$RD^{IE}_{SS,OA1}$	R&D stock pool performed in Ireland, within same sector outside area A1
$RD^{IE}_{OS,SA1}$	R&D stock pool performed in Ireland, outside sector within area A1
$RD^{IE}_{OS,OA1}$	R&D stock pool performed in Ireland, outside sector outside area A1
$RD^{IE,D}_{SS,SA1}$	R&D stock pool performed in Ireland by domestic plants within same sector within area A1
$RD^{IE,D}_{SS,OA1}$	R&D stock pool performed in Ireland by domestic within same sector outside area A1
$RD^{IE,F}_{SS,SA2}$	R&D stock pool performed in Ireland by foreign plants within same sector within area A2
$RD^{IE,F}_{SS,OA2}$	R&D stock pool performed in Ireland by foreign plants within same sector outside area A2
RD^{OECD}	R&D stock pool in OECD countries (excluding Ireland) within same sector
RD^{US}	R&D stock pool in the US within same sector
$RD^{OECD}_{SS,SA2}$	R&D stock pool in OECD countries (excluding Ireland) weighted by foreign presence within area A2
$RD^{OECD}_{OS,SA2}$	R&D stock pool in OECD countries (excluding Ireland) weighted by foreign presence outside area A2
SEGROWTH	Sectoral employment growth rate
$EDENSITY_{SA}$	Employment per km^2 within area A

Appendix B: Alternative econometric estimations

Table 3B: All Plants – Non DED Changing Sample

	(1)	(2)	(3)	(4)	(5)	(6)
RD^{PLANT}	0.019**	0.020**	0.019**	0.019**	0.018**	0.018**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{SS,SA}$	0.010**	0.021**	0.023**	0.014	0.001	-0.001
	(0.000)	(0.009)	(0.000)	(0.086)	(0.783)	(0.870)
$RD^{IE}_{SS,OA}$	0.004	-0.001	-0.002	0.008	0.008	0.067
	(0.210)	(0.929)	(0.755)	(0.552)	(0.553)	(0.066)
$RD^{IE}_{OS,SA}$		-0.037*	-0.024*	-0.031	-0.014	-0.015
		(0.044)	(0.040)	(0.125)	(0.121)	(0.127)
$RD^{IE}_{OS,OA}$		-0.199	0.158	-0.087	0.076	-0.012
		(0.560)	(0.507)	(0.802)	(0.438)	(0.852)
$EDENSITY_{SA}$		-0.105	0.141	-1.469	3.759	-18.817
		(0.847)	(0.701)	(0.606)	(0.211)	(0.048)
RD^{OECD}	0.021	0.008	0.003	0.019	0.012	0.018
	(0.573)	(0.781)	(0.911)	(0.678)	(0.681)	(0.566)
SEGROWTH	0.038	0.053	-0.011	0.021	0.029	0.050
	(0.635)	(0.632)	(0.897)	(0.883)	(0.712)	(0.543)
A:	*All*	*5km*	*10km*	*20km*	*50km*	*100km*
Obs.	2066	2066	2066	2066	2066	2066
Plants	945	945	945	945	945	945
Hansen stat.		5.524	2.821	3.247	7.393	5.481
Hansen p-value		0.137	0.588	0.355	0.193	0.360
R-SQ	0.048	0.033	0.043	0.024	0.043	0.050

Notes: (1) Boostrapped p-values in parentheses. (2) Estimated coefficients on constant term, time (year) dummies, and sector (Nace 2 digit) dummies not reported. (3) A: Size of Area; PLANT: own plant R&D; IE: R&D performed in Ireland. SS: same Nace 2-digit sector; OS: outside Nace 2-digit sector; SA: same area; OA: outside area; EDENSITY: employment density; (4) ** and * signify statistical significance at the 1 and 5 per cent levels, respectively.

Table 4B: Foreign Plants -– Non DED Changing Sample

	(1)	(2)	(3)	(4)	(5)	(6)
RD^{PLANT}	0.018**	0.018**	0.018**	0.018**	0.017**	0.018**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{SS,SA}$	0.006	-0.007	0.006	0.006	0.006	0.006
	(0.477)	(0.526)	(0.475)	(0.467)	(0.398)	(0.489)
$RD^{IE}_{SS,OA}$	0.010	0.004	0.010	0.010	0.008	0.010
	(0.116)	(0.554)	(0.127)	(0.122)	(0.176)	(0.124)
$RD^{IE}_{OS,SA}$	-0.028	-0.028	-0.027	-0.026	-0.025	-0.029
	(0.097)	(0.081)	(0.107)	(0.124)	(0.130)	(0.080)
$RD^{IE}_{OS,OA}$	0.411	0.087	0.399	0.398	0.404	0.402
	(0.093)	(0.688)	(0.119)	(0.109)	(0.105)	(0.112)
$EDENSITY_{SA}$	-0.089	0.935	-0.089	-0.089	-0.210	-0.084
	(0.824)	(0.069)	(0.828)	(0.827)	(0.579)	(0.834)
SEGROWTH	-0.123	-0.098	-0.082	-0.078	-0.140	-0.120
	(0.354)	(0.389)	(0.534)	(0.536)	(0.279)	(0.351)
RD^{OECD}	-0.001	0.007	0.186	0.152	0.031**	0.003
	(0.989)	(0.888)	(0.172)	(0.173)	(0.000)	(0.399)
A:	*10km*	*20km*	*10km*	*10km*	*10km*	*10km*
INT:	*PL*	*PL*	*OECD*§	*US*	*ORIGIN*	*Random*
Obs.	597	597	597	597	597	597
Plants	276	276	276	276	276	276
Hansen stat.	6.978	5.602	6.615	6.598	5.466	6.814
Hansen p-value	0.222	0.347	0.251	0.252	0.362	0.235
R-SQ	0.065	0.090	0.071	0.071	0.119	0.066

Notes: (1) Boostrapped p-values in parentheses. (2) Estimated coefficients on constant term, time (year) dummies, and sector (Nace 2 digit) dummies not reported. (3) A: Size of Area; PLANT: own plant R&D; IE: R&D performed in Ireland. SS: same Nace 2-digit sector; OS: outside Nace 2-digit sector; SA: same area; OA: outside area; EDENSITY: employment density; (4) ** and * signify statistical significance at the 1 and 5 per cent levels, respectively.

§ simple sum of R&D in OECD countries by sector, without considering the weighted scheme described in equation (8)

Table 5B: Domestic Plants and Local R&D by Nationality of Ownership

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RD^{PLANT}	0.016**	0.014**	0.016**	0.014**	0.016**	0.018**	0.016**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{SS,SA1}$	0.033**	0.009					
	(0.003)	(0.215)					
$RD^{IE}_{SS,OA1}$	-0.005	-0.013					
	(0.730)	(0.525)					
$RD^{IE}_{OS,SA1}$	-0.014*	-0.006	-0.014*	1.694	-0.006	-0.006	-0.003
	(0.026)	(0.446)	(0.012)	(0.316)	(0.252)	(0.112)	(0.583)
$RD^{IE}_{OS,OA1}$	0.508	0.192	0.318	0.086	0.241	-0.324	-0.206
	(0.050)	(0.434)	(0.658)	(0.609)	(0.667)	(0.718)	(0.838)
$RD^{IE,D}_{SS,SA1}$			0.028**	0.005	0.029**	0.032**	0.028*
			(0.002)	(0.630)	(0.007)	(0.000)	(0.039)
$RD^{IE,D}_{SS,OA1}$			0.019	0.002	0.015	0.134	0.132
			(0.764)	(0.979)	(0.806)	(0.220)	(0.206)
$RD^{IE,F}_{SS,SA2}$			0.018	0.004	0.005	0.013	0.011
			(0.070)	(0.699)	(0.651)	(0.057)	(0.460)
$RD^{IE,F}_{SS,OA2}$			-0.005	-0.005	-0.002	-0.046	-0.046
			(0.774)	(0.309)	(0.913)	(0.522)	(0.439)
$EDENSITY_{SA}$	0.710	1.766	0.687	-0.007	1.231	5.263	5.993
	(0.170)	(0.341)	(0.230)	(0.437)	(0.307)	(0.093)	(0.581)
RD^{OECD}	-0.058	-0.056	-0.039	-0.045	-0.040	0.101	0.085
	(0.236)	(0.214)	(0.578)	(0.302)	(0.513)	(0.652)	(0.641)
SEGROWTH	0.100	0.209*	0.028	0.168	0.146	-0.520	-0.293
	(0.396)	(0.028)	(0.878)	(0.279)	(0.398)	(0.577)	(0.695)
A1:	*10km*	*20km*	*10km*	*20km*	*10km*	*10km*	*10km*
A2:			*10km*	*20km*	*20km*	*50km*	*100km*
Obs.	1469	1469	1469	1469	1469	1469	1469
Plants	699	699	699	699	699	699	699
Hansen stat.	4.396	2.579	6.333	8.727	8.669	3.830	1.292
Hansen p-value	0.494	0.765	0.387	0.273	0.193	0.430	0.863
R-SQ	0.025	0.022	0.033	0.029	0.035	0.018	0.035

Notes: (1) Boostrapped p-values in parentheses. (2) Estimated coefficients on constant term, time (year) dummies, and sector (Nace 2 digit) dummies not reported. (3) A: Size of Area; PLANT: own plant R&D; IE: R&D performed in Ireland. SS: same Nace 2-digit sector; OS: outside Nace 2-digit sector; SA: same area; OA: outside area; EDENSITY: employment density; (4) ** and * signify statistical significance at the 1 and 5 per cent levels, respectively.

Table 6B: Domestic Plants and Foreign Presence as Transmitter of Foreign R&D

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RD^{PLANT}	0.017**	0.015**	0.016**	0.016**	0.016**	0.015**	0.016**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{OS,SA1}$	-0.012*	-0.006	-0.005	-0.006	-0.002	-0.001	-0.003
	(0.043)	(0.265)	(0.176)	(0.222)	(0.583)	(0.763)	(0.523)
$RD^{IE}_{OS,OA1}$	0.325	0.179	0.164	0.074	0.109	0.105	0.157
	(0.316)	(0.511)	(0.522)	(0.807)	(0.634)	(0.672)	(0.537)
$RD^{IE,D}_{SS,SA1}$	0.030**	0.025*	0.031**	0.031**	0.031**	0.027**	0.030**
	(0.002)	(0.027)	(0.001)	(0.000)	(0.002)	(0.006)	(0.002)
$RD^{IE,D}_{SS,OA1}$	0.123	0.012	0.005	0.009	0.002	0.011	0.015
	(0.190)	(0.823)	(0.929)	(0.871)	(0.972)	(0.831)	(0.781)
$RD^{OECD}_{SS,SA2}$	-0.000	0.001	0.001	0.002	0.018*	0.111	0.109
	(0.847)	(0.476)	(0.569)	(0.521)	(0.030)	(0.265)	(0.338)
$RD^{OECD}_{SS,OA2}$	-0.016	0.144	0.006	-0.001	-0.002	-0.003	
	(0.179)	(0.075)	(0.825)	(0.930)	(0.194)	(0.095)	
$EDENSITY_{SA1}$	0.823	1.425	6.287*	11.048*	29.420	-99.663	-16.385
	(0.181)	(0.273)	(0.029)	(0.046)	(0.226)	(0.347)	(0.836)
RD^{OECD}	0.024	-0.159	-0.049	-0.031	-0.052	-0.105	-0.115
	(0.854)	(0.156)	(0.410)	(0.565)	(0.332)	(0.302)	(0.306)
SEGROWTH	-0.165	0.397	0.192	0.168	0.209	0.330	0.287
	(0.676)	(0.166)	(0.275)	(0.336)	(0.227)	(0.216)	(0.281)
A1:	*10km*	*10km*	*10km*	*10km*	*10km*	*10km*	*10km*
A2:	*10km*	*20km*	*50km*	*100km*	*200km*	*300km*	*All*
Obs.	1469	1469	1469	1469	1469	1469	1469
Plants	699	699	699	699	699	699	699
Hansen stat.	7.152	6.704	5.566	6.621	6.038	9.663	9.175
Hansen p-value	0.307	0.460	0.591	0.469	0.535	0.208	0.164
R-SQ	0.011	0.030	0.040	0.038	0.033	0.018	0.009

Notes: (1) Boostrapped p-values in parentheses. (2) Estimated coefficients on constant term, time (year) dummies, and sector (Nace 2 digit) dummies not reported. (3) A: Size of Area; PLANT: own plant R&D; IE: R&D performed in Ireland. SS: same Nace 2-digit sector; OS: outside Nace 2-digit sector; SA: same area; OA: outside area; EDENSITY: employment density; (4) ** and * signify statistical significance at the 1 and 5 per cent levels, respectively.