EXPLORING THE LINK BETWEEN LOCAL AND GLOBAL KNOWLEDGE SPILLOVERS

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1 - Chapter 1: Introduction

The observed productivity differences across countries are arguably one of the main forces behind observed disparities in per capita income. The primary candidate driving such productivity differences is of course the state of technological know-how of a country.[1] In this regard, one of the main difficulties in quantifying technological know-how's true contribution to productivity is related to its very public nature and hence the possibility of externalities, where those other than the ones that generate the knowledge may benefit from it. There are now a large number of empirical papers that have investigated the existence of such knowledge spillovers. Some of these have focused on the influence of both technological and geographical distances on knowledge flows at the local level - as, for example, Jaffe (1986), Adam and Jaffe (1996) and Orlando (2004) – while others have been concerned with examining knowledge spillovers across countries, either directly or through such channels as FDI and trade; see, in particular, Helpman and Coe (1995) and Keller (2004) for a review. In general these studies have tended to show, on the one hand, that local spillovers are subject to distance decay effects and, on the other hand, that within country spillovers tend to be more prominent than between country spillovers, although the latter evidence has, to date, been mainly based on aggregate, industry-level studies rather than micro-level data.[2]

Importantly, however, one needs to note that existing empirical evidence is usually derived from treating local and global knowledge spillovers separately. Exceptions to this are the recent papers by Cassiman and Veugelers (2004), Branstetter (2006), and Griffith et al. (2007). Cassiman and Veugelers (2004) consider technology acquisitions by a sample of firms based in Belgium and observe that firms that source technology

[1] See Klenow and Rodriguez (1997), Caselli et al .(1996) and Hall and Jones (1999), for empirical evidence.

internationally generate local transfers more intensively, especially in the case of foreign affiliates based in Belgium. The authors also find, however, that, after controlling for access to international technology markets, foreign affiliates are less prone to transfer technology to the local economy. In contrast, Branstetter (2006) analyses both local and international knowledge spillovers through patent citations between Japanese firms and their affiliates located in the US and discovers that knowledge flows operate in both directions.

While the evidence provided by Cassiman and Veugelers (2004), and Branstetter (2006) sheds important light on the existence of international R&D spillovers, these studies do not measure the actual productivity gains due to these. In a recent paper, Griffith et al. (2007), provide such a productivity analysis using firm-level data to compare the productivity performance of UK firms with R&D labs located in the US relative to that of US firms with R&D labs based in the UK. Their results show that UK firms with research activity located in the US benefited from their US-based R&D activity through higher productivity levels. US firms with R&D activity in the UK, however, do not benefit from similar R&D spillovers emanating from their UK-based R&D labs. The authors conclude that, because of the overall higher technological capability of US firms, R&D spillovers are only significant when they flow from the most technologically advanced country (i.e., the US) to the least technologically advanced one (i.e., the UK). While these results highlight the magnitude of cross-border spillovers, one should note that Griffith et al.'s (2007) analysis does not take account of intra-national R&D spillovers.

In the present paper we argue that it is important to consider local and global knowledge spillovers together in a single analytical framework since the benefits derived from the growing internationalisation of knowledge are likely to be influenced by the local

[2] See the review by Keller (2004).

exposure to foreign innovations and technological improvements, as well as the local capacity to benefit from these. Our contribution to the existing literature in this regard is to consider a distinctive layer of transmission of knowledge represented by the spatial agglomeration of economic activities which can favour the absorption of both intra-national and international knowledge spillovers and the interaction between the two. In this paper we study such local and global knowledge spillovers together by considering the role played by geographic and technological distance in conjunction with that of international trade and FDI. To this end we make use of plant-level data for the Irish manufacturing industries spanning the time period 1990-1995 and focus on knowledge spillovers derived from R&D activity. Our research strategy borrows directly from Orlando (2004), who analyses the existence of local R&D spillovers by looking at the influence of R&D activity undertaken by distant plants making the distinction between technological distance (depending on whether R&D activity is carried out by plants within or outside a given industrial sector) and geographical distance measuring distance in kilometres between each pair of plant. However, unlike Orlando (2004), we avail of much more detailed geographic information concerning the location of each plant, allowing us to test for the existence of local R&D spillovers by considering distance-decay effects in a more precise manner. Moreover, we allow for local FDI, as well as trade, to act as additional potential channels of R&D spillovers.

Another major advantage of our data is that it is exhaustive, allowing us to measure all R&D activity performed within Ireland over our sample period, rather than for just a sub-sample of plants, and hence is able to capture all potential spillovers arising from local R&D activity. [3] We also avail of information regarding the nationality of ownership for each plant so that we are able to study domestic Irish plants and foreign affiliates based in

[3] See, for instance, the study by Orlando (2004) relies on sub-samples of particular sectors.

Ireland separately. Furthermore, given that we have the exact nationality of foreign affiliates, we can link the productivity performance of foreign affiliates based in Ireland with the R&D activity in their home country using OECD data on sector-level R&D activity. This allows us to analyse the role of foreign affiliates as vehicles for transmitting international R&D spillovers originated in their home country.

It should be noted that the use of plant-level data has been argued to represent a clear advantage over studies using aggregate FDI flows data at the sector level given that it provides a more precise measure of the influence of foreign presence on indigenous plants. In particular, an issue that has been traditionally faced by empirical researchers willing to consider trade and FDI simultaneously as channels for international R&D spillovers, is that these two variables are usually highly correlated, making it difficult to consider them jointly for empirical testing; see Mohnen (1996) and Keller (2002). We are able to circumvent this limitation by measuring the influence of FDI through their local presence instead of more aggregate FDI flows.

Ireland serves arguably as a particularly good case-study to measure the influence of foreign technological activity on local productivity levels because R&D spillovers have been shown to be traditionally more important for small rather than for large countries; see, for instance, Pottelsberghe de la Potterie and Lichtenberg (2001). Moreover, foreign plants in Ireland have been responsible for the largest share of R&D activity, representing approximately 70% of R&D spending over the period considered here. Nevertheless, despite the well known high growth rates of productivity in the Irish manufacturing sector, total R&D activity has been by international standards relatively low, suggesting the existence of other driving sources for productivity growth.[4] In this regard existing evidence

[4] In particular, during the period 1985-1994, which corresponds to the period covered by the present study, Irish total R&D spending (i.e. including private and public investment) represented, on average, 0,92% of GDP. By contrast, the rest of EU15 countries spent 1.92% of their GDP in R&D. During the period 1995-

tends to suggest that trade and FDI have played a major role in promoting Irish productivity over the past two decades or so. For instance, van Pottelsberghe de la Potterie and Lichtenberg (2001) provide evidence for Ireland showing that trade-embodied knowledge spillovers has been especially pronounced in Ireland compared to other OECD countries. A possible reason for this result could be Ireland's higher absorptive capacity of foreign knowledge spillovers, as has been suggested by Acharya and Keller (2007). More precisely, using US firm level data these authors find that Ireland is the primary beneficiary of US spillovers, even more so than Canada, and estimate that the elasticity of US R&D spillovers to be 46.5 per cent, compared to 24.5 per cent for the UK. Our analysis will allow us to shed greater light on whether R&D spillovers may have really played such a role.

The rest of the paper is organised as follows, in Section II we provide a description of the data used, in Section III we describe our main econometric results. Section IV concludes.

2 - Data Description and Summary Statistics

2 -1 A. Data Sources

We utilise information from three data sources collected by Forfás, the Irish policy and advisory board with responsibility for enterprise, trade, science, and technology in Ireland. As details of these are provided in Appendix A we only outline their most important attributes here. The first is the Forfás employment survey which is an exhaustive annual plant level survey with information on the location, nationality of ownership, sector of production, and yearly level of employment, and has been carried out since 1972.

2004, Irish spending has risen to 1.20% of GDP, remaining well below EU15 average which remained

The second source of information 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 varying between 60 and 80 per cent. 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 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 1986, 1988, 1990, 1991, 1993, and 1995, and Innovation Surveys 1990-1992 and 1994-1996, which collect information on R&D activity within Irish manufacturing. Importantly, these surveys are believed by Forfás to cover all R&D active firms, except for 1994, 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 use OECD data on R&D and bilateral trade between Ireland and its main OECD partners to measure 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 countries also constitute the main origins of FDI in Irish manufacturing industry since they

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broadly unchanged in relative terms. Sources: Eurostat and authors' computations.

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 gives us 21 sectors (shown in Table 1). Since we want to consider internationally as well as locally generated R&D spillovers simultaneously, we are thus limited to using this sector classification throughout our analysis.

2 -2 Calculation of Total Factor Productivity

Following Hall and Mairesse (1995), we base our empirical specification on a production-function framework. 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 arguably 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.[5] 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, details of which are given in Appendix B on our data.

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

2 -3 Local R&D Stocks

We are specifically interested in whether there are ‘spillovers’ from local and international R&D on plant level productivity. In this regard we assume, as Orlando (2004), a production function where plant-level R&D and R&D local spillovers related to the R&D activity of other plants belonging to the same industry influence productivity. Also following Orlando (2004), we distinguish between sectoral and geographical proximity, where sectoral proximity depends on whether plants belongs to the same sector of activity, while geographical distance is measured by the distance in kilometres between each pair of plant.

Our measure of R&D pool therefore combine the geographical dimension , sector dimension and nationality of ownership of the plant responsible for the R&D spending. Throughout the rest of the paper the R&D pool variables will therefore be assigned a superscript indicating whether the R&D is done in Ireland (IE) or outside Ireland (OECD or US). The superscript will also indicate, when relevant, whether the R&D performed in Ireland is done by domestic (D) or foreign plants (F). The geographical and sectoral scope of the R&D pool are indicated in the subscripts depending on whether the R&D is done inside or outside a given geographical area (where SA stands for *same area* and OA stands for *other areas*) and within or outside a given sector of activity (where SS stands for *same sector* and OS stands for *other sector*).

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, where the relevant stocks are the cumulative value of R&D expenditure of existing plants since 1986 depreciated at a rate of 15 per cent. 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 the sum of these four proxies constitute the total R&D stock in Ireland – except for a plant's own R&D pool which is excluded.

Of particular importance is the definition of area *A*. In this regard our data provides us with information on the location of all plants in terms of geographical areas termed DEDs. These DEDs have, on average, an area of 21 km^2 (standard deviation of 14 km^2), which, for Ireland, represents 3440 spatial units - see Map 1. Since we do not have the exact address of plants within DEDs we follow the suggestion made by Duranton and Overman (2004) and randomly allocate each plant to a unique coordinate within their DED. Using this coordinate we can then 'draw' a plant-specific circle with a given radius *r* for each plant and consider this the appropriate area *A* that allows us to construct our location specific spillover variables. Therefore, contrary to previous studies on R&D productivity spillovers, as for example Orlando (2004)[6], the geographic dimension considered here is based on a close approximation of the actual location of plants. One should note that this implies that the four spillovers variables can differ across plants by the fact that each plant is assigned a different location. The local R&D stocks variables are therefore time-varying plant-specific variables likely to capture the influence of geographical distance on local R&D spillovers.[7] The location of plants across Ireland are shown 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).

[6] Orlando (2004) has for his US data the county at firm-level and assigns these to county-centres to calculate out distances between plants.

[7] Moreover, one should keep in mind that, depending on the location of the plant and the definition of radius *r*, part of this area circle may necessarily be empty by construction if it slices into an area outside of the borders of Ireland, as, for example, off the coast.

2 -4 Global R&D Stocks

In order to capture international R&D spillovers we consider R&D activities outside of Ireland in terms of those 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 calculate our measure of international R&D pool for a given sector *j* at a given year:

$$RD^{OECD} = \sum_{c} w_{c} RD^{t} \qquad (2)$$

where RD_{ct} is the R&D stock of country c at time t and is calculated as the cumulative sum since 1986, deprecated at a rate of 15 per cent. The variable RD^{OECD} measures therefore the foreign stock of R&D and is used 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 measure have been shown to be sensitive to potential bias[8], we also experimented with using the geographical distance between Ireland and its OECD partners as a weighting scheme for international R&D spill in a way similar to Keller

[8] See Keller (1998).

(2002). The results obtained in this case were fairly similar to those of our benchmark measure so that we only report the latter.

2 -5 Descriptive Statistics

Combining all our data sets resulted in a sample of 1790 plants with 4308 observations for the period 1990 through 1995, excluding 1994. Of these 22 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. As can be seen, only 12% of plants have declared R&D spending over the period considered. Nevertheless, there is 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, 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% 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 Machiney 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.

3 - A. Econometric Analysis

3 -1 Econometric specification

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

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

where *TFP* is total factor productivity, RD^{PLANT} is a plant's own R&D stock, ($RD_{SS,SA}^{IE}$, $RD_{SS,OA}^{IE}$, $RD_{OS,SA}^{IE}$, $RD_{OS,OA}^{IE}$) are the local spillovers variables, RD^{OECD} is the global (or international) spillover variable, ***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. One should note that we have summarised definitions of all our variables used throughout our econometric analysis in Appendix C.

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, as outlined in Section II and detailed in Appendix 2. 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, sector specific time invariant, and county specific time invariant determinants of productivity, respectively.[9] [10]

Given that we can be fairly confident that all our control variables in are exogenous, we estimate (3) using OLS. An alternative approach may have been to estimate productivity directly by including all factor inputs in (3) and using value added as the dependent variable and employing the GMM estimator proposed by Blundell and Bond

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

[10] While, given our set of controls and the fact that the spillover variables exclude a plant's own R&D, our spillover variables are arguably exogenous, we nevertheless experimented with using lagged instead of contemporaneous values. Although the use of these reduced samples sizes considerably, reassuringly all estimates were qualitatively the same and quantitatively very similar. Detailed results are available from the authors.

(1998).[11] However, given the lack of variation over time for our very short panel this approach would not have been feasible.

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 (mostly sectoral and regional) 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 under OLS. In order to take account of this we follow Bertrand et al (2003) and instead implement an alternative test derived from block bootstrapping. More precisely, let β^* be the estimated coefficient under OLS, $se(\beta^*)$ its standard error, and t the resultant t-statistic. We construct a bootstrap sample by drawing observations with replacement from all geographical areas and sectoral units, then run OLS on this sample, obtain the estimate β^b, and construct the absolute t-statistic:

$$t^b = \frac{abs(\beta^* - \beta^b)}{se(\beta^b)} \qquad (4)$$

Drawing 500 boostrapped samples and subsequent values of the absolute t-statistic, we reject the null hypothesis that $\beta=0$ at the 95 per cent confidence level if 95 per cent of the t^b are smaller than t. We report relevant p-values for this test in all our estimations.[12]

[11] One should note that Griffith et al (2007) also experiment with this alternative approach in their study, but find similar results as in using OLS the Buettner (2003) version of the Olley and Pakes productivity proxy.

[12] We also experimented with allowing the error terms to be correlated within DEDs and sectors as suggested by Bertrand et al (2003). The results obtained were essentially the same.

3 -2 Econometric Results

We start off by abstracting from any nationality of ownership differences and estimate (1) for our total sample of plants for various specifications in Table 3. In the first column we also initially ignore any local dimension of the R&D stock within Ireland and consider the area A to 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, reassuringly, own R&D stock has a positive and significant effect on productivity. One also finds that the total R&D stock within the 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, LP, has, however, no significant impact. Similarly sectoral business cycles do not 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. We first start off with a relatively small area, namely a 5km radius circle, the results of which are shown in the second column. One should note that we also include all other appropriate regional controls to ensure that our within the same sector/area spillover proxies are not capturing any other sectoral and/or area effects, as discussed earlier. 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. Given that such spillovers only occur within the same sector, it also indicates that technological distance matters, although, given our level of sectoral aggregation, in a relatively broad sense.

In columns 3 through to 6 we then proceeded to enlarge the circle along pre-defined radiuses, namely to 10, 20, 50, and 100kms.[13] 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 50 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. 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^{OECD} .

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 plants and serve as transmitters of new technologies, see Görg and Strobl (2001) and Görg and Greenaway (2004) for a review of the literature. Multinationals 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

[13] 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. For instance, defining the local area as that within 10 km of a plant showed no evidence of local within sector R&D spillovers.

via their activity and interactions with local companies.[14] As discussed by Keller (2004), FDI-spillovers may thus be considered, like R&D spillovers, as a potential channel favouring knowledge transfer across national boundaries.

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 to 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. [15] Even if this were not the case, one would normally expect multinational firms to have more access to global knowledge pools given the relationships between different plants belonging to the same multinational, see Keller (2004). 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. For instance, Adam and Jaffe (1996) show that plants belonging to the same company benefit from firm-level R&D activity. It follows then that, when measuring the benefits of R&D investment and R&D spillovers on plants' productivity, one is likely to miss an important part of the story if one only looks at own-plants and local R&D stocks, especially in the case of multinationals. However, the aforementioned authors also find that R&D spillovers are negatively influenced by distance decay effects and vanish as the number of plants belonging to the same company grows. This argument may also apply here since foreign affiliates based in Ireland may simply constitute a small link in the whole production process of multinationals and be producing products very different from that of (very distant) plants located in other countries. Adam and Jaffe (1996) call this the 'dilution' of R&D across multiple plants.

[14] See Barrios et al. (2006) for an analysis of the local dimension of FDI-related spillovers in the Irish case.
[15] 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).

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.[16] The results show that, while own R&D remains significant, there is, in contrast to the overall sample, no longer any trace of local R&D spillovers. This lack of spillover effects continues to hold 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 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.

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 trade-weighting scheme described in equation (8). As can be seen from the third column of Table 4, this variable similarly shows no significant impact of 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. Again, however, this alternatively measure, shown in the fourth column, remains insignificant.

One could also argue, as discussed earlier, 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

[16] We also experimented with the smaller radius of 5 km, but this also produced insignificant local effects.

within the same sector of the origin country described in Section III as potentially spillover creating, the results of the inclusion of this are shown in the fifth column of Table 3. [17] 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.

As a robustness check of this latter result, we use the same variable but this time, for each Nace 2 digit sector, randomly distribute its values across countries. In doing this we follow the idea developed by Keller (1998) concerning the influence of international R&D spillovers through trade found by Helpman and Coe (1995). Keller argues that by matching countries depending on their trade link, one is likely to capture other-than-trade related R&D spillovers. In order to make his point, Keller considers instead randomly allocated bilateral trade flows and still find a positive and significant influence of R&D spillovers suggesting that trade only provide part of the story and that other, more general, mechanisms must be at play explaining the existence of international R&D spillovers. Using a similar approach, we reassign OECD countries' R&D stock by sector by distributing randomly the country of origin of the foreign affiliate for a given sector of activity.[18] Reassuringly, our results from the final column of Table 4, where the coefficient is now insignificant, however, suggest that the country of origin of foreign affiliate located in Ireland positively influence their productivity level.[19]

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, their own R&D

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[17] As indicated in Section II, these countries are Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the UK and the US and nearly concern all the foreign presence in Irish manufacturing for the period considered.

[18] The approach used for the random distribution of countries of origin is…[put reference here]

[19] We also repeated this experiment with alternative random distribution and still found insignificant results. Result available from the author upon request.

stock significantly increases 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. 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 may put a strain on local inputs, such as skilled labour. While this appears to be compensated for by positive spillovers for R&D that is technologically close, this is not the case for knowledge created that has relatively little to do with a plant's own production process. One may want to note in this regard, that once one considers these two countervailing forces, the overall benefits per square kilometre are close to zero, indicated by the relative size of the coefficients of these two variables.

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 may potentially 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.[20] 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 20 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 essentially outweighs any per square kilometre benefits. 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 in 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 make distance less relevant for R&D spillovers. We thus increased the spatial scope of the area for which such 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 additionally included a measure of local employment density for 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. Interestingly, though, the employment density variable displays a positive and significant coefficient, suggesting the presence of wider agglomeration economies which are not necessarily related to R&D activities, in line with the findings of Ciccone and Hall (1996).

[20] One should note that while we, in order to simplify the readability, only report the results when decomposing the R&D spillovers for the same sector (i.e., $RD^{IE}_{SS,SA}$ and $RD^{IE}_{SS,OA}$) 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.

As discussed earlier, by definition multinational plants are part of a greater multi-plant corporation, where the headquarters and other affiliates are located outside 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 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 located near a domestic plant the total R&D stock within the same sector in the origin country of the foreign plant. One should note in this regard 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 of nationality 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, $RD^{OECD}_{SS,OA}$. As before, given that the geographical areas considered are plant-specific and based on distance measured between each pair of plant, these variables defined are unique for each plant considered.[21]

The results of including $RD^{OECD}_{SS,SA}$ and $RD^{OECD}_{SS,OA}$ 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 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. 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, $RD^{OECD}_{SS,SA2}$. Further enlarging A2 to 200km radius means further increasing the value of the coefficient on $RD^{OECD}_{SS,SA2}$ from 0.004 to 0.027, while remaining significant. It is also noteworthy that this coefficient is higher than that on the local R&D spillovers emanating from R&D undertaken by domestic Irish plants. However, an additional increase to a radius of 300km renders it insignificant.[22] 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 greater geographic scope than for domestically produced R&D stock, domestic plants can indeed benefit from R&D spillovers arising from local multinationals.

[21] Note that, in order to keep to 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 $RD^{OECD}_{SS,SA}$ and $RD^{OECD}_{SS,SA}$ variables.

[22] We also experimented with a radius of 250km, but this also rendered the coefficient insignificant.

4 - Concluding Remarks

In this paper we linked local and global knowledge spillovers to analyse their impact on plants' productivity using the case study of Ireland. Arguably 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 existence and relative importance of both local and global R&D spillovers in the context of productivity analysis at plant level. Secondly, while possible interactions between the two types of spillovers have been left untouched by existing empirical studies, our paper shows that these interactions do exist and are especially important for domestic plants.

Our results show that while domestic plants benefit from local R&D spillovers, these spillovers are spatially bounded. Furthermore, domestic plants do not appear to benefit from R&D done by foreign affiliates based in Ireland. This finding can be related to Cassiman and Veugelers (2004) who find for Belgium that foreign affiliates do in fact generate less local transfers of technology than their domestic counterparts once superior access to international technology markets is accounted for. We also discover that there can be interactions between two major, as advocated by Keller (2004), channels of knowledge spillovers, namely FDI and international R&D activity. In particular, the evidence here suggests that foreign affiliates allow domestic plants to tap into their countries' knowledge pool through their presence on the local market rather by their own local R&D activity. Moreover, this positive, indirect, effect of foreign presence also deteriorates with geographical distance, where its geographical scope is much wider than that derived from R&D spillovers from other indigenous plants. In contrast, we find no evidence that foreign multinationals in Ireland are recipients of local R&D spillovers, but do benefit from the R&D stock in their origin country.

5 - Tables

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**	0.020**	0.020**	0.020**	0.020**	0.020**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{SS,SA}$	0.011**	0.008**	0.012**	0.004	0.003	0.003
	(0.000)	(0.000)	(0.002)	(0.260)	(0.344)	(0.274)
$RD^{IE}_{SS,OA}$		-0.005	-0.002	-0.004	-0.005	-0.003
		(0.278)	(0.620)	(0.322)	(0.174)	(0.184)
$RD^{IE}_{OS,SA}$	0.000	-0.002	-0.003	-0.004	-0.000	0.024
	(0.922)	(0.382)	(0.500)	(0.340)	(0.988)	(0.264)
$RD^{IE}_{OS,OA}$		-0.013	0.108	-0.032	0.002	0.023
		(0.908)	(0.214)	(0.614)	(0.970)	(0.598)
$EDENSITY_{SA}$		0.056	0.326	0.865	3.344	4.778
		(0.446)	(0.132)	(0.154)	(0.156)	(0.570)
RD^{OECD}	-0.009	-0.012	-0.016	-0.013	-0.012	-0.010
	(0.710)	(0.622)	(0.490)	(0.614)	(0.638)	(0.708)
SEGROWTH	0.117	0.115	0.110	0.118	0.118	0.123
	(0.124)	(0.150)	(0.152)	(0.126)	(0.114)	(0.112)
A:	*All*	*5km*	*10km*	*20km*	*50km*	*100km*
Obs.	4308	4308	4308	4308	4308	4308
Plants	1790	1790	1790	1790	1790	1790
R-SQ	0.20	0.20	0.20	0.20	0.20	0.21

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)
$RD^{IE}_{SS,SA}$	0.004	-0.004	0.004	0.004	0.005	0.005
	(0.336)	(0.382)	(0.323)	(0.335)	(0.299)	(0.099)
$RD^{IE}_{SS,OA}$	-0.005	-0.011	-0.004	-0.005	-0.006	-0.013
	(0.600)	(0.232)	(0.632)	(0.571)	(0.544)	(0.129)
$RD^{IE}_{OS,SA}$	0.008	-0.000	0.008	0.008	0.007	0.001
	(0.146)	(0.993)	(0.149)	(0.152)	(0.231)	(0.761)
$RD^{IE}_{OS,OA}$	-0.029	-0.167	-0.032	-0.027	-0.043	-0.167
	(0.794)	(0.073)	(0.772)	(0.808)	(0.693)	(0.145)
$EDENSITY_{SA}$	0.293	1.420	0.290	0.302	0.265	0.201
	(0.305)	(0.073)	(0.340)	(0.289)	(0.347)	(0.057)
RD^{OECD}	0.013	0.017	-0.106	-	0.019**	0.000
	(0.720)	(0.635)	(0.361)		(0.010)	(0.911)
RD^{US}	-	-	-	-0.086	-	-
				(0.312)		
SEGROWTH	0.197	0.204	0.159	0.164	0.196	0.207
	(0.137)	(0.121)	(0.212)	(0.183)	(0.134)	(0.113)
A:	*10km*	*20km*	*10km*	*10km*	*10km*	*10km*
INT:	*NONE*	*NONE*	*Total OECD§*	*US*	*ORIGIN*	*RANDOM*
Obs.	1250	1250	1250	1250	1250	1250
Plants	520	520	520	520	520	520
R-SQ	0.36	0.35	0.36	0.36	0.37	0.36

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)
RD^{PLANT}	0.013**	0.013**	0.013**	0.013**	0.013**	0.013**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{SS,SA1}$	0.010**	0.003				
	(0.004)	(0.364)				
$RD^{IE}_{SS,OA1}$	-0.004	-0.003				
	(0.422)	(0.386)				
$RD^{IE}_{OS,SA1}$	-0.012*	-0.009	-0.011*	-0.009	-0.012*	-0.012*
	(0.018)	(0.100)	(0.015)	(0.073)	(0.011)	(0.012)
$RD^{IE}_{OS,OA1}$	0.087	-0.003	0.098	-0.005	0.082	0.088
	(0.392)	(0.960)	(0.277)	(0.943)	(0.350)	(0.308)
$RD^{IE,D}_{SS,SA1}$			0.012**	0.006	0.011**	0.011**
			(0.000)	(0.202)	(0.002)	(0.002)
$RD^{IE,D}_{SS,OA1}$			-0.001	-0.000	-0.001	-0.002
			(0.848)	(0.961)	(0.685)	(0.552)
$RD^{IE,F}_{SS,SA2}$			-0.005	-0.009	-0.008	-0.002
			(0.226)	(0.056)	(0.063)	(0.525)
$RD^{IE,F}_{SS,OA2}$			-0.001	-0.002	-0.002	-0.002
			(0.826)	(0.553)	(0.508)	(0.304)
$EDENSITY_{SA1}$	0.441	0.808	0.517*	0.995	0.427	0.392
	(0.068)	(0.292)	(0.032)	(0.177)	(0.104)	(0.094)
$EDENSITY_{SA2}$					0.440	5.507*
					(0.494)	(0.011)
RD^{OECD}	-0.031	-0.028	-0.033	-0.032	-0.035	-0.030
	(0.296)	(0.364)	(0.318)	(0.307)	(0.267)	(0.333)
SEGROWTH	0.089	0.092				
	(0.254)	(0.284)				
A1:	*10km*	*20km*	*10km*	*20km*	*10km*	*10km*
A2:			*10km*	*20km*	*20km*	*50km*
Obs.	3058	3058	3058	3058	3058	3058
Plants	1270	1270	1270	1270	1270	1270
R-SQ	0.17	0.17	0.17	0.18	0.18	0.19

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)
5.1.1 RD^{PLANT}	0.013**	0.013**	0.013**	0.013**	0.013**	0.013**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$RD^{IE}_{OS,SA1}$	-0.011*	-0.012*	-0.011*	-0.011*	-0.012**	-0.011*
	(0.014)	(0.012)	(0.015)	(0.016)	(0.008)	(0.014)
$RD^{IE}_{OS,OA1}$	0.110	0.110	0.111	0.122	0.133	0.123
	(0.171)	(0.174)	(0.165)	(0.133)	(0.099)	(0.130)
$RD^{IE,D}_{SS,SA1}$	0.011**	0.011**	0.011**	0.010**	0.011**	0.012**
	(0.003)	(0.004)	(0.002)	(0.003)	(0.002)	(0.002)
$RD^{IE,D}_{SS,OA1}$	-0.000	-0.000	-0.000	-0.000	0.000	-0.000
	(0.956)	(0.935)	(0.927)	(0.979)	(0.986)	(0.994)
$RD^{OECD}_{SS,SA2}$	0.000	0.000	0.002	0.004*	0.027*	0.013
	(0.753)	(0.552)	(0.074)	(0.029)	(0.018)	(0.373)
$RD^{OECD}_{SS,OA2}$	-0.008	-0.003	0.002	-0.003	-0.000	0.000
	(0.251)	(0.829)	(0.764)	(0.696)	(0.741)	(0.761)
$EDENSITY_{SA1}$	0.474	0.432	0.396	0.451	0.519*	0.489*
	(0.063)	(0.104)	(0.091)	(0.063)	(0.024)	(0.045)
$EDENSITY_{SA2}$		0.077	0.100	0.090	0.107	0.092
		(0.370)	(0.242)	(0.275)	(0.202)	(0.286)
RD^{OECD}	-0.027	-0.032	-0.035	-0.026	-0.046	-0.041
	(0.400)	(0.307)	(0.264)	(0.417)	(0.130)	(0.183)
SEGROWTH	0.070	0.182	4.931*	12.753	37.298	-20.589
	(0.396)	(0.786)	(0.023)	(0.082)	(0.164)	(0.892)
A1:	*10km*	*10km*	*10km*	*10km*	*10km*	*10km*
A2:	*10km*	*20km*	*50km*	*100km*	*200km*	*300km*
Obs.	3058	3058	3058	3058	3058	3058
Plants	1270	1270	1270	1270	1270	1270
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.

6 - Figures

Figure 1: Breakdown of Ireland into DEDs

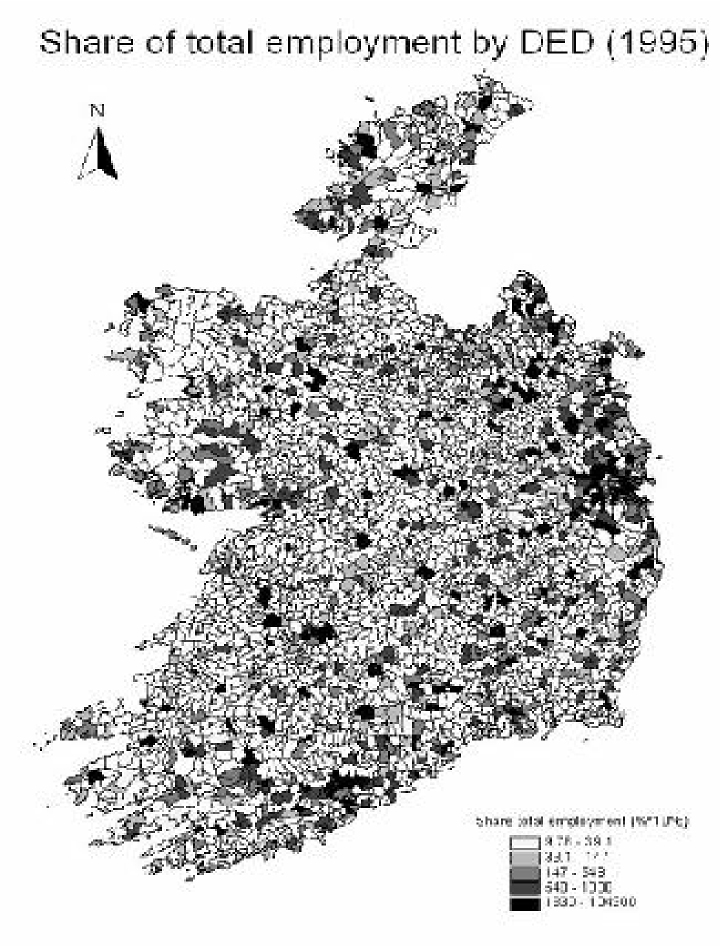


Figure 2: Location of All Plants (1995)

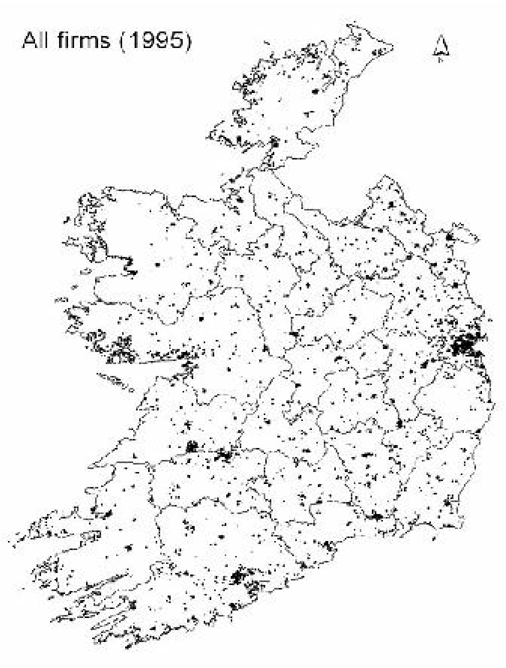
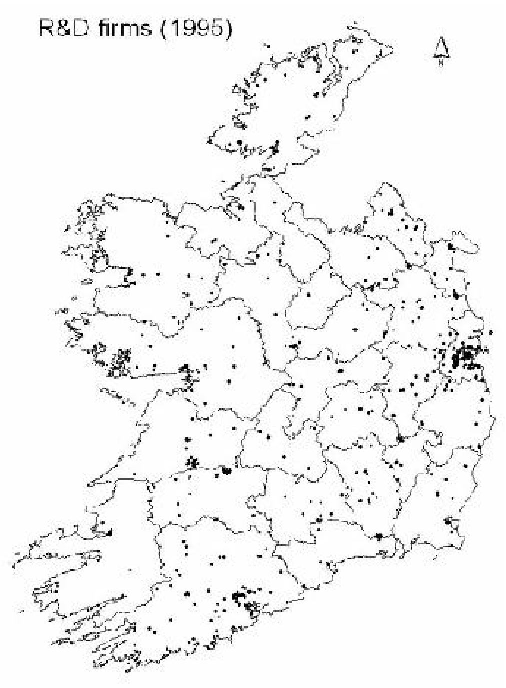


Figure 3: Location of Plants doing R&D (1995)



7 - References

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Annex 1: Detailed Data Description

Forfás Employment Survey: This is an annual plant level survey for manufacturing, conducted since 1972, with information on the nationality of ownership, sector of production, location, start-up year, and level of employment each year. The response rate to this survey is argued by Forfás to be essentially 100 per cent so that the data can be seen to cover the entire population of manufacturing plants and can thus serve as a complete list of all active (and formally active) plants in Irish manufacturing since 1972. One should also note that Forfás defines foreign plants as plants that are majority-owned by foreign shareholders, i.e., where there is at least 50 per cent foreign ownership. While, arguably, plants with lower foreign ownership should still possibly considered to be foreign owned, this is not necessarily a problem for the case of Ireland since almost all inward foreign direct investment has been greenfield investment rather than acquisition of local firms, see Barry and Bradley (1997).

Irish Economy Expenditure Survey : This is an annual survey of larger plants in Irish manufacturing with at least 20-30 employees, although a plant, once it is included, is generally still surveyed even if its employment level falls below the 20-30 employee cut-off point. The response rate to this survey has varied between 60 and 80 per cent. The information available from this source that is relevant to the current paper are the level of output, employment, total wage bill. From 1990 onward the IEE also collected data on the capital stock of a firm. In calculating value added we follow Buettner (2003) and calculate this as total output minus cost of materials, where cost of materials is calculated as total operating costs (labour costs, cost other services, and cost of raw materials) net of labour costs and R&D expenditure.

Research and Development and Innovation Surveys: The Research and Development Surveys we use were carried out in 1986, 1988, 1990, 1991, 1993, and 1995 and contain information on R&D activity within Irish manufacturing. Additionally, the Innovation Survey 1990-1992, conducted in 1992, also provides information on R&D expenditure of plants for 1992, one of the two years in the 1990-1995 sequence in which no R&D survey was carried out. While there was also an Innovation Survey 1994-1996, the question regarding R&D activity in 1994 is retrospective and thus arguably not as comparable to with the other data. We thus have information on R&D activity of plants in Irish manufacturing for the years 1986, 1988, 1990-1993, and 1995. Importantly, these surveys are believed by Forfás to cover all R&D active firms, and thus can be argued to be exhaustive with regard to these seven years.

Annex 2: Calculation of Total Factor Productivity

Olley and Pakes' (1996) estimation procedure is based on a dynamic single agent industry model and assumes that plants maximize the expected discounted value of future net cash flows. In essence the authors assume a production function of each plant *i* takes the following form:

$$y_{it} = \alpha_0 + \alpha_l l_{it} + \alpha_k k_{it} + \omega_{it} + \upsilon_{it} \quad \text{(B1)}$$

where y_{it} is value added, l_{it} is labour, k_{it} is the capital stock, ω_{it} is the unobserved productivity state and υ_{it} is a serial uncorrelated productivity shock or a potentially serially correlated measurement error. While labour, *l*, is completely variable, capital, *k*, is assumed to be quasi-fixed. At the beginning of any period a plant i observes its productivity state and kit. One should note that the important difference between ω_{it} and υ_{it} is that it is only the latter that affects a plant's investment decision making. Using expectations about the net present value plants will decide to shut down or continue operating. If they continue operating it will choose *l* and how much to invest in physical capital, where physical capital evolves in a deterministic process based on investment in accordance with the perpetual inventory method. The shock υ_{it}, driven by an exogenous first order Markov process, is then realized after the choices concerning the inputs are made. Using the monotonicity property of the investment policy function in unobserved productivity Olley and Pakes (1996) show how to get consistent estimates of the variable inputs, which in turn can then be used to obtain the coefficient on capital.

In his extension of the Olley and Pakes (1996) procedure to incorporate R&D, the author assumes that the productivity state ω_{it} still evolves according to a controlled Markov process, but that the distribution of the following period's productivity is increasing also in the amount of R&D expenditure. He then shows that not only does the invertibility of the investment policy function still hold, but also that the R&D investment function is invertible.

In terms of implementing Buettner's (2003) extension one should note that the first stage estimation of Olley and Pakes (1996) remains unaltered. More precisely, if one writes unobserved productivity as:

$$\omega_{it} = \tilde{\omega}(i_{it}, k_{it}) \quad \text{(B2)}$$

where *i* is investment, then the production function can be rewritten as:

$$y_{it} = \alpha_0 + \alpha_l l_{it} + \varphi(i_{it}, k_{it}) + \upsilon_{it} \quad \text{(B3)}$$

where

$$\phi_t = \varphi(i_{it}, k_{it}) \equiv \alpha_0 + \alpha_k k_{it} + \tilde{\omega}(i_{it}, k_{it}) \quad \text{(B4)}$$

Estimates of equation (3) will then give a consistent estimate of α_l and ϕ_t. However, since the form of ϕ_t is not known it must first be approximated. We follow Buettner (2003) and Griffith et al (2007) and use a series estimator using higher order terms to approximate it.[23]

Buettner's (2003) second stage exploits the fact that in his underlying model the choice of the distribution of function of productivity, ψ_t, in t-1 can be expressed as a function of the optimal choice of ι_{it} and the state variable ω_{it}

[23] As in Griffith et al (2007) we used third order series expansion. However, experimentation of with higher orders made little difference to the results.

$\psi_{it} = \tilde{\psi}(\omega_{it}, k_{it})$ (B5)

The second stage estimation then becomes:

$y_{it} = f(\vartheta_{it-1} - \alpha_k k_{it-1}, k_{it}) + \tau_{it} + \upsilon_{it}$ (B6)

where the productivity innovation τ_{it} is uncorrelated with k_{it}. One can then estimate *f()* by running non-linear least squares on a non-parametric function in $\vartheta_{it-1} - \alpha_k k_{it-1}$ and k_{it}.

Two aspects with regard to this estimation procedure are noteworthy here. Firstly, this second stage does not actually rely on the use of R&D data. Buettner (2003) also proposes an alternative second stage that explicitly uses data on R&D expenditure. However, he also emphasizes that this alternative importantly relies on the assumption that R&D is uncorrelated with the error terms. In his data, as in ours, where R&D is used in the construction of the value added measure, this is unlikely to be the case. Secondly, this procedure does not explicitly take selection into account. In this regard Buettner (2003) offers a slight extension of the approach that does, however, since our data consisting mainly of large plants, exhibited very little exits over the sample period we did not implement this alternative to calculate total factor productivity values.[24]

With estimates of α_l and α_k at hand from the two steps outlined above one can then easily calculate total factor productivity from (B1). In terms of implementing the procedure we grouped the plants in our sample according to the Nace 2 digits classification and ran it separately for each of these groups. This grouping, shown in Table, constitutes a categorization of the type of production of plants at a level below one-digit and above two-digit NACE Rev. 1. While we would have ideally liked to have used greater disaggregation to allow for greater plant heterogeneity, this would have left us with unfeasible sample sizes for the non-linear least squares estimation.

[24] Over our sample period only slightly over 1 per cent of the plants shut down operation. Unsurprisingly, experimenting with the selection version of the estimation procedure produced practically the same results.

Annex 3: Variables definition

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 km² within area A
$EDENSITY_{SA1}$	Employment per km² within area A1
$EDENSITY_{SA2}$	Employment per km² within area A2