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Location and Network Effects on Innovation Success: Evidence for UK, German and Irish Manufacturing Plants

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Abstract

Recent developments in the new economic geography and the literature on regional innovation systems have emphasised the potentially important role of networking and the characteristics of firms' local operating environment in shaping their innovative activity. Modelling UK, German and Irish plants' investments in R&D, technology transfer and networking, and their effect on the extent and success of plants' innovation activities, casts some doubt on the importance of both of these relationships. In particular, our analysis provides no support for the contention that firms or plants in the UK, Ireland or Germany with more strongly developed external links (network or technology transfer) develop greater innovation intensity. However, although inter-firm links also have no effect on the commercial success of plants' innovation activity, intra-group links are important in terms of achieving commercial success. We also find evidence that R&D, technology transfer and networking inputs are substitutes rather than complements in the innovation process, and that there are systematic sectoral and regional influences in the efficiency with which such inputs are translated into innovation outputs.

1. Introduction

Recent developments in endogenous growth theory have stressed the importance of technological progress to economic advance (e.g. Romer, 1990). Linking technical progress and economic growth, however, is the process of innovation, sometimes defined as the commercial application of new or existing knowledge. Traditionally, innovation was understood as a linear process starting with new technological discovery and ending with new products. More recently, however, it has been recognised that innovation is perhaps best understood as a continuous and evolutionary process (Nelson and Winter, 1982), shaped by institutional routines and social conventions (Morgan, 1997) and the intensity and extent of organisational and inter-personal interactions (Grabher and Stark, 1997). The importance of innovation, and the potential roles of institutions and policy to improve nations' innovation record, has prompted considerable discussion of individual National Innovation Systems (most notably, Nelson, 1993) and discussion of different nations' innovation policies (e.g. Nelson, 1993; Metcalfe, 1997; Roper, 1999). More recently, in the context of the EU debate surrounding regional competitiveness, these ideas have also been applied to the innovation systems of individual regions (e.g. Braczyk et al., 1998; Fritsch and Lukas, 1999; Morgan, 1997).

A key question in this strongly policy oriented debate has been on the appropriateness of alternative regional innovation strategies to differing regional contexts (see, for example, Hassink, 1993; Asheim and Dunford, 1997). Referring specifically to Morgan (1997), Asheim and Dunford (1997) characterise supporters of a network-based regional development strategy as believing that it "offers the prospect of the development by devolved, intermediate institutions like regional development agencies of policies to enhance the social capital … and increase the innovative capacity of less developed regions" (p. 451). In this view, local inter-firm networks and links between companies and local organisations outside the supply chain (e.g. higher education institutions, development agencies) provide a framework for intra-regional learning and knowledge transfer (Lazonick, 1993)[1]. Also, and perhaps more important in a regional context, are relationships within which inter-regional technology or knowledge transfers can take place[2]. Wong (1992), for example, in an assessment of the role of multinational enterprises (MNEs) in Singapore, argues that technology transfer through MNE plants may stimulate innovative activity in locally-owned companies beyond that generated by their own R&D and local networking activity[3]. Other empirical research suggests that such technology transfers may also explain the higher innovation rates recorded for multi-plant corporations in both the UK and Switzerland compared with their independent indigenous counterparts (Goddard et al., 1986; Brugger and Stuckey, 1987).

Although the potential importance for innovation of local networks and technology transfers have been widely acknowledged, empirical studies have tended to adopt a

[1] In a previous study we have shown that such network linkages provide a direct boost to the number of new and improved products introduced by UK manufacturing plants (Love and Roper, 1999).
[2] One possible indicator of the potential importance of inward technology transfer to an area is the proportion of local patent applications made by non-residents. Regional evidence of this sort is limited, but in the Republic of Ireland in 1994, for example, OECD figures suggest that only two per cent of patent applications were made by national residents (Roper and Hewitt-Dundas, 1998, pp. 20-22).
[3] For example in the context of quality improvement, Wong comments: 'the very process of the MNC implementing its stringent quality/performance control system over the output supplied by the sub-contractor may provide valuable feedback that will greatly facilitate technological learning by the subcontractor. The more extensive the diagnostic efforts provided by the MNC buyer, the stronger the learning facilitation will be'.

descriptive or discursive rather than statistical approach (see for example, Ashcroft et al., 1994; Roper and Thanki, 1995 and the case-studies in Braczyk et al., 1998). Where international comparisons of regional innovation performance or capability have been made they have tended to compare specific regions with similar industrial or structural characteristics (e.g. Jowitt, 1991; Hassink, 1993; Cooke and Morgan, 1994). Although these regional case-studies and comparisons have identified a number of factors which differentiate successful and unsuccessful regional innovation systems (Cooke, 1992) their principal weakness is their inability to identify the *relative* importance of each of these factors[4]. Our object here is therefore to address four empirical questions:

Question 1: How important are firm-specific, regional and (national) industry factors in determining the intensity of firms' R&D, networking and technology transfer activities?

Question 2: Are local networking, technology transfer and R&D substitutes or complementary inputs to the innovation process?

Question 3: How important are firms' R&D, networking and technology transfer activities in determining the level and success of firms' innovative activity?

Question 4: Do regional and industry factors influence the efficiency with which R&D, networking and technology transfers are translated into innovation outputs?

The motivation for considering these questions lies in their potential importance for the content and emphasis of regional development policies. How much resource, for example, should be allocated to local network development as opposed to encouraging R&D or technology transfer? Roper (1998), for example, suggests that currently less than 2 per cent of the industrial development budget in Ireland is targeted at building collaboration or co-operation between firms. Similarly, improvements in what aspects of firms' local operating environment are likely to lead

[4] Heidenreich and Krauss (1998), for example, identify what they regard as the key strengths of the Baden-Wurttemberg innovation system (i.e. a dense network of innovation related institutions, a closely linked supply chain, the education system, a progressive attitude to industrial relations, and an effective banking system) but are able to say little in terms of the relative importance of these various influences on innovation potential.

to the greatest payoff in terms of the level of innovative activity? How do these payoffs differ between different types of regional economies?

The remainder of the paper is organised as follows. Section 2 describes our conceptual framework that is based on the idea of the innovation production function (Acs and Audretsch, 1988; Geroski, 1990; Harris and Trainor, 1995). This provides the link between firms' investments in technology transfer, networking and R&D and innovation outputs. Firms' regional operating environment can then influence innovation outputs through its effect on firms' investments in technology transfer, networking and R&D, and also through its effect on the efficiency with which these investments are translated into innovation outputs (Love and Roper, 1999)[5]. Section 3 describes the main data sources used in the analysis and Section 4 outlines the empirical results. The empirical analysis covers the UK, Germany and the Republic of Ireland to take account of differences in both national and regional contexts.

2. Conceptual Framework

Attempts to model firms' innovation activity typically start from standard behavioural assumptions that suggest that investment in technological development activities take place when the results of these investments (i.e. innovations) are expected to earn positive post-innovation price-cost margins. Moreover, the scale or intensity of these investments is usually asserted to vary positively with the expected returns (see Geroski, 1990, for a discussion). In the spirit of the literature on networks and 'learning regions' we envisage here that there are three possible routes by which firms may obtain the knowledge necessary to undertake innovation: R&D, technology transfer and networking. R&D we take to mean research or developmental activity carried out by the enterprise alone, and on its own premises. Networking we regard as a collaborative or sub-contract relationship between plants unrelated by ownership (Roper et al., 1996). Technology transfer, we define as collaboration between plants within a group of companies. In the main, this latter type of relationship will be inter-

[5] In the context of an examination of innovation in Northern Ireland, for example, Harris and Trainor (1995) found that an urban location was associated with increased R&D investment but had no effect on the efficiency with which these R&D inputs were transformed into innovation outputs.

regional although there may, of course, be multiple plants from one group in a specific region. In each case, standard behavioural assumptions suggest that firms' willingness to invest in these activities will depend both on the expected return, firms' ability to appropriate the profits of any development and the ease with which the development can be made or exploited. This suggests that firm i's investments in R&D (R_i), networking (N_i) and technology transfer (T_i) may be represented by 'factor intensity' equations of the form:

$$\begin{aligned}
R_i &= \gamma_{11} + \gamma_{12}T_i + \gamma_{13}N_i + \gamma_{14}\pi_i^e + \gamma_{15}L_{ij} + \gamma_{16}L_{ik} + \gamma_{17}Z_i + \varepsilon_{1i} \\
T_i &= \gamma_{21} + \gamma_{22}R_i + \gamma_{23}N_i + \gamma_{24}\pi_i^e + \gamma_{25}L_{ij} + \gamma_{26}L_{ik} + \gamma_{27}Z_i + \varepsilon_{2i} \qquad (1) \\
N_i &= \gamma_{31} + \gamma_{32}R_i + \gamma_{33}T_i + \gamma_{34}\pi_i^e + \gamma_{35}L_{ij} + \gamma_{36}L_{ik} + \gamma_{37}Z_i + \varepsilon_{3i}
\end{aligned}$$

Where π^e_i is the expected level of post innovation returns of firm i and L_{ij}, L_{ik} and Z_i are vectors of regional, industry and plant-specific factors which regional case-studies suggest may influence firms' ability to appropriate or exploit the benefits of any innovation (e.g. Braczyk et al., 1998). Plant-specific factors might include, for example, skill levels, nationality of ownership, group membership etc. Following Geroski (1990) and others, the vector of plant-specific characteristics will also include indicators of firms' market power designed to capture any Schumpeterian plant size effect. The regional (L_{ij}) and industry (L_{ik}) vectors will include aggregate parallels of similar variables as well as institutional or structural indicators reflecting, for example, regional investments in higher education provision or public sector R&D spending.

Assuming expectations are rational, the 'factor intensity' equations (1) can be estimated directly by replacing π^e_i with actual post-innovation profit margins. In the estimating equations the size and significance of parameter vectors γ_{i5}, γ_{i6} and γ_{i7} will indicate the relative importance of regional, industrial and plant-specific factors (see Research Question 1 above). Parameters γ_{i2} and γ_{i3} will suggest the type of relationship which exists between firms' R&D, networking and technology transfer activities (see Research Question 2 above)[6].

Regional and industrial factors may also be important, however, in determining the efficiency with which knowledge acquired through R&D, technology transfer and networking is translated into innovation outputs (I_i). These effects may either be additive or may depend on interactions between firms' activities and their operating environment. Audretsch and Feldman (1996), for example, provide evidence that R&D spillovers are more important in areas with concentrations of knowledge intensive industries. Similarly, the importance of milieu-type effects, in which the locational proximity of firms may lead to the development of positive networks or inter-dependencies, may depend on firm size or ownership (Maillat, 1991). The potential for such effects suggests a general form of innovation production function where the level of innovation outputs (I_i) depends on the intensity of firms' R&D, networking and technology transfer activities and other plant specific and locational influences. That is for firm i, located in region j:

$$I_i = \varphi_0 + \varphi_1 R_i + \varphi_2 T_i + \varphi_3 N_i + \chi_1 I_j + \chi_2 I_k + \chi_3 Z_i + \theta_1 R_i I_j + \theta_2 T_i I_j + \theta_3 N_i I_j + \mu_i \quad (2)$$

where, following Audretsch and Feldman (1996), we also allow for interactions between the level of innovative activity in the region (I_j) and firms' technological development activities. A central test of the hypothesis that technology transfer and networking intensity are important to innovation will be the empirical significance of the φ_2 and φ_3 parameters (Research Question 3 above). Similarly, the estimated χ_1, χ_2, and χ_3 parameters will indicate the importance of regional, industrial and firm-specific characteristics on the efficiency with which plants' investments in R&D, networking and technology transfer are translated into innovation outputs. Finally, the θ_1, θ_2, and θ_3 parameters will capture any similar effects that depend on interactions between firms' technological development activity and the level of innovative activity in their host region (Research Question 4 above).

[6] Dutch evidence, reported in Audretsch et al. (1996), for example, suggests that the relationship between different types of R&D may differ between industries; in low technology industries, internal and external R&D were substitutes; in high-technology industries they were complements.

3. Definitions and Data

The main plant-level data source used in the estimation is the Product Development Survey (PDS), which contains comparable information provided by 1700 UK plants, 1300 German plants and 500 Republic of Ireland businesses (see Roper et al., 1996). In the UK, sampling for the PDS was structured by plant sizeband, industry and 'super-region' (Figure 1). In Germany, the original sampling for the PDS was structured by plant sizeband and industry for the former West and East Germany. Response rates were sufficient, however, to allow representative results to be obtained for each of the six German super-regions identified by Lammers (1994). Plants responding to the PDS provided information on a number of indicators of innovation outputs and success including the total number of product changes and the proportion of sales derived from new and/or improved products. The proportion of plants introducing new or improved products over the 1991-94 period was highest in Germany, and in particular in the former East Germany. Other German regions, particularly Northern Germany and Baden-Wurttemberg also had high proportions of innovating plants (Table 1). The average number of new or improved products and innovation intensity (i.e. the number of product changes per employee) also varied significantly between super-regions, although there was less regional variation in the average proportion of plants' sales derived from new or improved products (Table 1).

Innovating plants that responded to the PDS also provided information on their R&D activities, and whether they had engaged in either networking or technology transfer activities during seven individual elements of the product innovation process. In the estimation, we use the standard indicator of the intensity of plants' R&D activity, i.e. R&D employment as a percentage of total employment in the plant. Our measures of technology transfer and networking intensity are more experimental, and are based on the extent of plants' external linkages during the different elements of the innovation process. More specifically, we calculate an intensity score for technology transfer and networking, ranging from zero for a plant which engaged in no technology transfer or networking, to 100% for a plant that was involved in technology transfer or networking during all seven elements of the product innovation process (Table 1) [7].

Three other sets of variables play an important role in the estimation. First, we include a range of other *plant-specific* variables derived from the PDS database which other studies have suggested are important in influencing plants' innovation capability (see, for example, Kleinknecht, 1996). Large plants, for example, seem more likely to innovate than their smaller counterparts (Oakey et al., 1988; Santarelli and Sterlacchini, 1990)[8]. In addition, external ownership has been shown to be a potentially important influence although the empirical evidence is somewhat ambiguous about whether external-ownership boosts or constrains innovative activity[9]. Organisational flexibility has also been strongly linked to the ability to innovate (e.g. Fairtlough, 1994), and in the estimation we include indicators of workforce quality, the nature of plants' production process and the organisation of R&D, intended to reflect the degree of internal flexibility within the plant.

The second set of variables included in the estimation is intended to normalise for the possible effects on innovation of technological opportunity within the plant's sector and any concentration effects related to plant and industry size. PDS data, aggregated to 2-digit industry level within each country, is used to generate variables to represent technological opportunity (e.g. the proportion of innovating firms, the proportion of firms with R&D departments, sectoral R&D intensity etc.). Concentration indicators are intended primarily to capture the potential effects of barriers to entry on innovation although the direction of this type of effect is uncertain. On one hand, barriers to entry may encourage innovation by providing a secure, low-risk market environment in which firms can undertake and benefit from innovation (Love et al,

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[7] The seven elements of the product development process distinguished in the PDS were: identification of new or improved products; prototype development; final product development; product testing; production engineering; market research; and marketing strategy.

[8] Related evidence comes from a series of studies by Acs and Audretsch who examined the relationship between size and firms' innovation intensity (i.e. the number of innovations made). Typically, they observe either a quadratic or cubic relationship with innovation intensity peaking at some intermediate plant size. In similar work on Scottish data, Love et al (1996) found maximum innovation intensity (innovations per employee) occurred at 1245 employees.

[9] Arguments that external ownership restricts the autonomy of local plants limiting their willingness and ability to innovate (Malecki, 1980; Howells, 1984; and, Harris, 1991) have been contradicted by two recent studies, based on data for Northern Ireland and Scotland, which concluded that externally-

1996); on the other hand, barriers to entry may act as a shield, allowing firms to maintain their level of profitability even with low levels of innovation. Data for the concentration measures was taken from the UNIDO international database at 4-digit level (3-digit level for Ireland), and combined with PDS data to estimate national market shares for individual plants.

The final set of variables included in the estimation is that intended to capture any milieu or spill-over type effects offered by plants' operating environment[10]. For example, Shefer and Frenkel (1998) on the basis of evidence from Northern Israel, suggest that agglomeration advantages, represented by population density, are positively associated with firms' innovation activity. Similarly, Audretsch and Feldman (1996) suggest that local R&D spillovers are more significant where there are concentrations of high-tech or R&D intensive industries. Other regional variables included in the analysis, mirroring the arguments made earlier at the plant level, were the percentage of plants undertaking R&D and the availability of graduates within the regional labour force. Unemployment rates and relative income levels were also included as general indicators of regional prosperity and local market sophistication (Gudgin, 1995).

4. Empirical Analysis

Model estimation was undertaken in two stages with the estimation of equations for technology transfer, networking and R&D intensity preceding that of the innovation production function. As the technology transfer, networking and R&D intensity variables are limited rather than continuous, the appropriate estimation technique is Tobit, with lower and upper tail censoring at zero and 100.

Tables 2, 3 and 4 give the estimated Tobit equations for technology transfer, networking and R&D intensity for innovating firms in the UK, Germany and the

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owned establishments were more likely to innovate than their locally-owned counterparts (Harris and Trainor, 1995; Love *et al*, 1996).

[10] Feldman (1994, p. 51) summarises the potential importance of this type of factor as follows:

Republic of Ireland[11]. The first notable features of the intensity equations are the strong and predominantly negative signs on the simultaneous terms relating to R&D, technology transfer and networking activity. These suggest that R&D, networking and technology transfer are generally substitutes although there are national differences in the strength of this substitution effect. In the UK and Ireland, for example, there is strong evidence of substitution between networking and technology transfer and, controlling for the effects of external-ownership and group membership, between technology transfer and R&D (see also Love and Roper, 1999). In Germany, a similar although statistically weaker, substitute relationship exists between plants' networking and technology transfer activities although there is little evidence of any clear relationship between plants' R&D and other technological development activities.

The differences in these results suggest that UK and Irish companies are more willing *ceteris paribus* to substitute external sources of technological activity (i.e. technology transfer and networking) for internal activity (i.e. R&D) than German firms. One possible explanation is that this reflects different managerial practices or attitudes. Roper (1997), for example, suggests that the innovation strategies of German small firms are more risk averse and less market responsive than those of UK and Irish small businesses. This is reflected in German small firms' more 'managed' and strategic approach to product development, in contrast to the more responsive and often time-critical developments undertaken by UK and Irish small firms. Technology transfer or networking activity may allow a firm to accelerate the product development process but is likely to carry additional risks in terms of intellectual property rights and/or contract compliance - a risk/reward balance which seems less likely to appeal to more risk averse German businesses. An alternative, and perhaps more persuasive explanation for the greater willingness or necessity for UK and Irish firms to substitute external for internal technological development activity relates to

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"Taken together, these complementary institutions provide resources and knowledge inputs to the innovation process, generate positive externalities and spill-overs which lower the cost of developing new innovations, and reduce the risk associated with innovation".

[11] Limitations in the PDS mean that the intensity equations for networking and technology transfer can only be estimated for those plants undertaking some product innovation. R&D intensity equations can, however, be estimated for all plants. Comparison between the R&D intensity equations estimated for innovators only and for all plants suggested no significant differences in the estimated coefficients. The profitability proxy proved statistically insignificant in all estimations, and was dropped from the analysis.

skill shortages. The empirical results indicate a strong and consistent relationship between the level of graduate employment in plants in each country and R&D intensity (Tables 2, 3 and 4). Roper et al. (1996), on the basis of evidence from the PDS, also noted that the innovation activity of 32 per cent of UK and Irish manufacturing firms was constrained by skill shortages compared to only 22 per cent of German firms[12]. In this situation, UK and Irish firms may find it more necessary to substitute external technological development activity for internally conducted R&D, particularly if they are operating on a tight timescale[13].

R&D intensity is also positively related to plant size in Germany, although there was no clear relationship in the UK, and some suggestion of a negative relationship in Ireland. The apparent effect of external ownership on R&D intensity also differed between countries although this effect is conditional on the level of R&D intensity among indigenously-owned companies[14]. In the UK, external ownership is associated with reduced R&D intensity, with no significant effect in Ireland[15]. More surprising, given the high level of R&D intensity among indigenously-owned German firms, is that external ownership in Germany is positively associated with increased R&D intensity. One possible explanation, however, is that the strong German skill base has attracted the more research-intensive activities of multi-national enterprises. External ownership was also positively associated with higher levels of technology transfer activity and, in the UK, with higher network intensity.

As intuition suggests, being a part of a group is generally positively associated with technology transfer. More intriguingly, in all three countries group membership is also positively associated with networking, an activity which at first sight might be expected to be principally the preserve of SMEs. The willingness of group member plants to network with other companies may suggest that such plants have more

[12] Differences in the proportion of plants reporting skill shortages were greatest for larger businesses: 40 per cent of UK plants with more than 500 employees reported significant skill shortages compared to only 14.0 per cent of similar German plants. Source: Roper et al. (1996), Table 7.3, pp 48.
[13] Further support for this argument is provided by the reasons why firms undertake networking and technology transfer. Roper et al. (1996) found that ‘faster development’ was a much more important consideration for UK and Irish plants than their German counterparts.
[14] External-ownership is defined as ownership of the plant from outside the respective country.
[15] This latter result suggests that the relatively high levels of R&D spending among externally-owned plants in Ireland, noted for example by Quinlan (1995), can be explained largely or wholly by plants’ characteristics regardless of ownership.

experience and/or more developed systems for managing external relations, and may have a broader range of functions over which such networking could occur. It may also suggest that plants which are members of groups – often owned from outside the region – may be more embedded in their host region than would be suggested merely by examining supply chain linkages.

Plants' market share and average plant size in each sector were also included in the intensity equations to capture any scale or market concentration effects. Both variables proved unimportant in the estimation suggesting that in each country barriers to entry provide little effective incentive for plants to increase their technology investments. Technological opportunity in the sector (represented by the sectoral (i.e. 3-digit) average level of the dependent variable) proved a much more important determinant of plants' R&D, networking and technology transfer intensities respectively. The consistency and strength of this effect for all three countries may suggest that this is not merely the standard technological opportunity effect to be expected among sectors of differing technological intensity, but may indicate the presence of positive sectoral spillovers occurring not merely in R&D (Audretsch and Feldman, 1996), but also in technology transfer and networking.

Inclusion of regional variables in the intensity equations was limited to the UK and Germany (although see Roper (1998a) for a sub-regional analysis for Ireland)[16]. The first notable feature of the estimated coefficients on the regional terms is that unlike Shefer and Frenkel (1998) and Brouwer and Kleinknecht (1996), we find no evidence of any positive agglomeration effect on the intensity of firms' technological development activity. Secondly, there was little evidence of any significant link between the intensity of plants' technological development activity and indicators of regional prosperity (i.e. relative GDP per capita, unemployment rates), public sector R&D investment, or the availability of graduates in a region. In terms of the main research questions outlined earlier these results suggest that - in Germany and the UK at least – plants' investments in R&D, technology transfer and networking are only very weakly conditioned by their regional operating environment. Much more important are the nature of the industry in which the plant is operating and the

[16] In the empirical analysis the level of regional analysis was not the 12 'super' regions but 28 individual regions i.e. 11 UK standard regions, 16 German Länder, and Ireland

specific characteristics of the plant itself. These results also suggest that the contrasts between regional levels of R&D, technology transfer and networking activity, noted in Table 1, are primarily the result of technological opportunity in the markets in which plants located in the region are operating and the more specific characteristics of the plants themselves. Agglomeration effects and the type of factor-related effects anticipated in the regional innovation system literature seem, at least from our data, relatively unimportant in influencing plants' technology investments[17].

Even if regional influences are having a relatively small effect on the level of R&D, networking and technology transfer intensity, however, it is still possible that they may be contributing to the efficiency with which the inputs to the innovation process are combined to produce innovation outputs. Table 5 therefore gives estimates for the innovation production function (i.e. equation 2) where the dependent variables are *innovation intensity* (i.e. the number of product innovations per employee) and *innovation success* (i.e. the proportion of sales attributable to new and improved products). These output-based dependent variables are selected as important indicators not merely of the of the extent of plant-level innovation, but of the commercial success of such activity on which much of the dynamism of regional economies depends.

The model outlined earlier relates firms' factor investment decisions to final innovation outcomes and suggests two possible behavioural scenarios. First, firms' decisions about factor intensities may be made taking into account their likely impact on innovation outcomes, i.e. factor intensity decisions may implicitly take account of the structure of the innovation production function. Alternatively, because of limited information or the uncertainty implicit in the innovation process, factor investment decisions may be independent of later stages of the innovation process. In this case, the decision process is essentially sequential with the factor intensities being predetermined with respect to the innovation production function. The distinction between these two alternatives is important in that it suggests different modelling approaches. If decisions about factor intensities do take into account the structure of

[17] This clearly depends to some extent on the spatial scale of the regions included in the analysis. For example, Harris and Trainor (1995) do find some effect of this type when they split their sample into urban and rural areas.

the innovation production function, a simultaneous equation approach is relevant. If instead, the factor intensity decisions are essentially separate from subsequent developments (i.e. the level of innovation outputs is caused by, but does not cause, the factor intensities) the factor intensity decision and the innovation production function can be modelled separately.

To test the hypothesis that our innovation output indicators are exogenous with respect to the factor intensity investment decision we follow a procedure suggested by Smith and Blundell (1986). This involves simultaneously estimating a Tobit model for factor intensity and a regression model for the innovation output indicator and including the innovation output indicator as an independent variable in the Tobit model. Exogeneity of the innovation output indicator is then indicated by a t-test of the hypothesis that the error covariance is zero (see Greene, 1995, p. 610 for operational details). Conducting these tests for each country and factor intensity suggests that the innovation output indicators are consistently exogenous with respect to the factor intensity equations[18]. In statistical terms this suggests that the factor intensity decisions are independent of the innovation production function and that the factor intensity equations and innovation production function can be modelled separately. In more behavioural terms, this result suggests that due either to uncertainty or limited foresight the factor intensity investment decisions are made with little regard or knowledge of subsequent innovation outcomes.

R&D, networking and technology transfer intensity are included in the equations as explanatory variables both in natural terms and, reflecting the substitutability noted earlier, in the form of a series of interaction terms[19]. In the estimation, R&D intensity proves important in terms of innovation intensity in the UK and Germany but is of more limited importance in determining innovation success. Technology transfer intensity, on the other hand, is less important as a determinant of the extent of plants' innovation activity but does contribute positively to the subsequent commercial

[18] Values of the t-statistic on the error covariance term for R&D intensity, technology transfer intensity and network intensity respectively were as follows: UK -0.078, -0.945, -1.090; Germany 0.034, -0.785, 0.042; Ireland -0.142, 0.071, 0.110.
[19] Terms were also initially included to reflect any interaction effects between the level of innovative activity in the region and R&D, technology transfer and networking intensity. These proved wholly insignificant in the estimation.

success of plants' innovation activity. One possibility is that technology transfer allows plants to make higher quality innovations that then enjoy more commercial success. Alternatively, technology transfer may allow firms to make innovations more quickly and obtain first mover advantages in terms of increased sales and potential profitability. More surprising, particularly given the extensive discussion in the regional innovation system literature, is the lack of significance of the estimated coefficients on inter-firm networking. Indeed, our results suggest that in none of the three countries does the intensity of plants' networking activity have any significant effect on either the extent or success of plants' innovation activity (Table 5). This casts some doubt on the potential value for promoting innovation of network-based policy initiatives of the type advocated by Morgan (1997), and exemplified in his description of recent policy developments in Wales (see also Asheim and Dunford, 1997). It also reflects the findings of Brouwer and Kleinknecht (1996) who, on the basis of a Dutch data, found "against all expectations … very little evidence that firms which collaborate on R&D or acquire external technological knowledge have a higher innovation output" (p. 118). Brouwer and Kleinknecht interpret their result as casting doubt on the value of the EU policy focus on the promotion of R&D networking and collaboration, a contention strengthened by the findings of the current study. However, they also suggest an alternative interpretation due to Teece (1988), who argued that networking may be undertaken by weaker innovators in response to internal resource constraints. If this were the case, the positive – albeit insignificant - coefficients on the networking intensity variables in the innovation success equations (Table 5) would suggest that networking is of some value in compensating for internal resource deficiencies (Brouwer and Kleinknecht, 1996, p. 118).

Apart from R&D, networking and technology transfer intensity the innovation production functions also suggest that a number of plant specific characteristics are important determinants of the extent and success of plants' innovation activity. As in previous studies, our estimation suggests that innovation intensity varies inversely with plant size (Acs and Audretsch, 1988; Love et al, 1996; Love and Ashcroft, 1999), although there is weaker evidence of any relationship between plant size and innovation success. External ownership and group membership both have a negative effect on innovation intensity; in Germany and Ireland, however, external ownership is positively associated with innovation success. The implication is that although plants which are externally-owned or group members tend to make fewer innovations than indigenously-owned firms these innovations are typically more successful. As suggested earlier this may be due either to the higher quality of innovations made by externally-owned plants or to the speed with which these are introduced to the market place. The possibility of a positive relationship between the quality of a plant's innovations and market success is also suggested by the positive relationship between the presence of in-house R&D and higher levels of graduate employment.

As in the R&D, technology transfer and networking equations, the technological characteristics of the sector – represented in the innovation production functions by sectoral innovation intensity and success – were also important. The implication of this is that the efficiency with which innovation inputs were converted into innovation outputs and innovation successes was strongly sectorally dependent. Unlike the intensity equations, however, regional innovation activity also proved important in some of the innovation production functions. In Germany, plants located in regions where the average innovation intensity and innovation success was higher tended to be more innovation intensive and successful themselves. In the UK, there was little evidence of any regional effect on innovation intensity, but firms operating in regions where innovators tend to be more successful tended also to be more successful themselves.

5. Summary and Conclusions

The empirical results discussed above indicate that there are some national differences both in the determinants of 'factor intensity' inputs into the innovation process, and in the innovation production functions themselves. Nevertheless, it is possible to broadly summarise the key findings with respect to the four research questions posed earlier.

Question 1: Plant and sectoral level factors are important in determining the intensity of R&D, technology transfer and networking activity at the plant level, but there is little evidence of regional effects.

Question 2: Where there is any significant effect, the relationship between R&D, technology transfer and networking is one of substitution rather than complementarity in the innovation process.

Question 3: R&D intensity is important in terms of innovation intensity in the UK and Germany but is of more limited importance in determining innovation success. Technology transfer has little role as a determinant of the extent of plants' innovation activity but does contribute positively to the subsequent commercial success of plants' innovation activity. Networking appears to have no positive role to play.

Question 4: There is some evidence of both sectoral and regional influences on the efficiency with which R&D, technology transfer and networking are translated into innovation outputs, and these effects vary between countries.

Recent developments in the new economic geography, and the literature on regional innovation systems (e.g. Braczyk et al., 1998), have emphasised the potentially important role of networking and the characteristics of firms' local operating environment in shaping their innovative activity. Modelling UK, German and Irish plants' investments in R&D, technology transfer and networking, and their effect on the extent and success of plants' innovation activities, casts some doubt on the importance of both of these relationships. In particular, our analysis provides no support for the contention that firms or plants in the UK, Ireland or Germany with more strongly developed external links (network or technology transfer) develop greater innovation intensity. In terms of the link between plants' external collaboration and the extent of innovative activity these results reflect the earlier findings of Brouwer and Kleinknecht (1996) using Dutch data. Our results go beyond their analysis, however, by suggesting that although inter-firm links also have no effect on the commercial success of plants' innovation activity, intra-group links are important in terms of achieving commercial success.[20]

In terms of the EU debate about regional innovation policies these results have two main implications. First, as Brouwer and Kleinknecht (1996) argue, these results cast

[20] Note, however, that there is some evidence from the UK that networking may increase the *number* of innovations at plant level, *ceteris paribus* (Love and Roper, 1999).

doubt on the validity of the current emphasis of EU technology policy on promoting international collaboration in R&D and innovation projects. Secondly, the results suggest the limitations of the type of network-based regional regeneration strategies which have been advocated by Morgan (1997) and others (although see Hudson, 1997). Indeed, our results suggest that, because of the tendency for plants to substitute networking activity for in-house R&D, measures that promote networking may have the perverse effect of reducing the extent and sales success of plants' innovation activity. It is possible, however, that encouraging networking activity may influence other dimensions of firms' innovation activity not considered here. It may be, for example, that networking allows firms to accelerate their product development activity reducing time to market and increasing the rate of return. Alternatively, networking may allow an element of risk-sharing allowing firms to undertake developments that would be too costly or risky to undertake alone.

Our empirical analysis also highlights the dependency of the level of innovative activity in a region on the sectoral composition of manufacturing in the area and the characteristics of the region's plants. Where a region's manufacturing sector is dominated by small firms, or sectors where little technological opportunity exists, a low level of innovation activity may be anticipated. External ownership is associated in our analysis with relatively low levels of efficiency in translating technological developments resulting from R&D, networking and technology transfer into innovation outputs: however, innovation by externally-owned plants is typically more commercially successful than that by locally-owned businesses. Other aspects of the operating environment within a region were substantially less important in determining plants' level of R&D, networking and technology transfer activity. In particular, our analysis provides little support for the empirical importance for firms level of investment in R&D, networking and technology transfer of agglomeration effects, regional prosperity, government R&D spending or the availability of graduate labour. Stronger regional effects were evident on the efficiency with which these inputs to the innovation process were translated into innovation outputs. In Germany, plants located in regions with high levels of innovation activity and success tended themselves to both innovate more and to be more successful. A similar positive spill-over effect was also evident in terms of innovation success in the UK although we could find no evidence of any such effect in terms of the extent of plants' innovative activity.

These results provide cold comfort for more disadvantaged regions. Structural weaknesses in such regions, in particular a preponderance of low value added industry and low productivity small firms (e.g. Roper, 1998b), are likely to lead to a low level of R&D, networking and technology transfer activity. This, in turn, is likely to lead to a low level of innovative activity limiting plants' growth potential and the ability of the region to generate positive spillovers in the innovation process. Structurally stronger regions, however, in which R&D, networking and technology are more widespread seem likely to generate higher levels of innovative activity and more substantial local spillovers. Our evidence also suggests, however, that attempts to improve firms' regional operating environment through measures such as training and government R&D investment are likely to have little effect on firms' investments in R&D, networking and technology transfer. More positive in the long term seem initiatives designed to address the underlying structural weaknesses of the region through targeted inward-investment and by measures designed to upgrade the innovation capability of individual plants.

Figure 1: UK, German and Irish Super-regions Used in the Product Development Survey

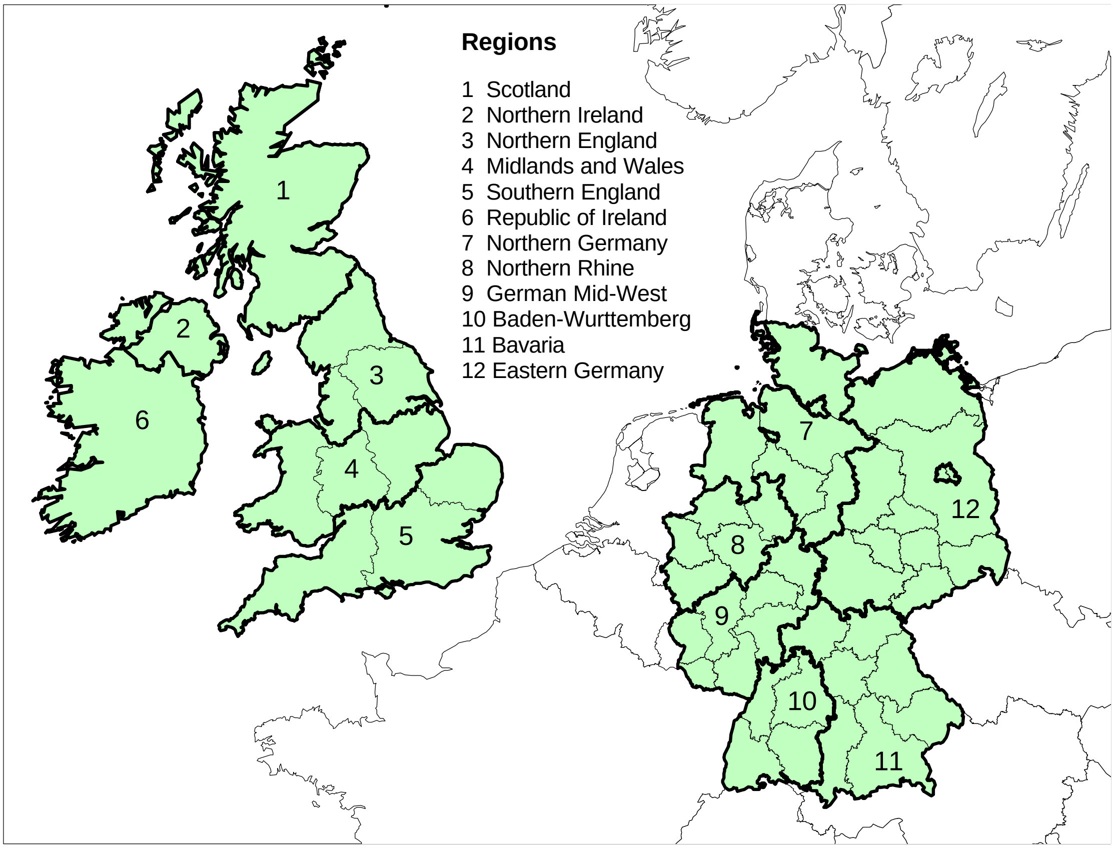

Table 1: Innovation, Networking and Technology Transfer Indicators by Super-Region

	N	Product Innovators	Innovators Only: Number of Product Changes	Sales of New/Improved Products	R&D Intensity	Technology Transfer Intensity	Networking Intensity	Innovation Intensity
		% firms	No.	%	%	%	%	No per 100
Scotland	223	52.8	19.4	52.0	4.3	10.5	13.8	0.194
Northern Ireland	257	60.3	11.6	59.2	2.9	12.3	10.7	0.175
Northern England	217	65.2	37.8	54.2	2.6	8.0	12.6	0.351
Midlands and Wales	224	65.5	26.4	49.9	3.1	9.6	9.4	0.653
Southern England	212	61.6	17.2	53.7	6.1	9.5	10.9	0.347
Republic of Ireland	404	66.5	14.4	52.8	3.8	12.0	11.2	0.226
Northern Germany	87	72.3	13.4	46.5	3.2	3.1	10.6	0.094
Northern Rhine	205	61.8	30.6	49.8	3.9	2.8	9.2	0.155
German Mid West	121	71.4	14.0	41.8	2.7	4.0	13.4	0.136
Baden-Wurttemberg	170	73.5	22.6	46.4	2.7	2.9	11.0	0.179
Bavaria	202	62.6	19.9	44.1	4.7	0.7	13.0	0.144
Eastern Germany	399	81.6	32.8	77.7	7.1	6.8	13.5	0.476
Memo Items:								
UK	1133	*63.4*	25.7	52.8	4.0	9.3	11.1	0.429
Ireland	404	*67.7*	14.4	52.8	3.8	12.0	11.2	0.226
Germany	1186	*71.4*	23.0	51.5	4.1	3.4	11.7	0.201

Notes

1. A product innovator was a plant introducing a new or improved product over the 1991 to 1994 period. Sales of new or improved products relates to the proportion of plants' sales in 1995 derived from products which were either new or improved over the 1991 to 1994 period. R&D intensity is R&D employment as a percentage of total employment in the plant. Technology transfer and networking intensity are defined in the text. Innovation intensity is the number of product changes (i.e. the number of new or improved products) per 100 employees.

2. Figures relate to manufacturing plants with more than 20 employees in 1993. Survey responses are weighted to give regionally representative results

Source: Product Development Survey

Table 2: Tobit Models of R&D, Networking and Technology Transfer Intensity in the UK

	Innovators Only		
	R&D	Technology Transfer	Networking
Constant	2.498	-100.347	-16.184
	(0.592)	(-1.797)	(-0.711)
Factor Intensities			
Technology Transfer Intensity (%)	-0.0664		-0.3715
	(-5.244)		(-5.000)
Networking Intensity (%)	-0.0054	-0.4896	
	(-0.378)	(-2.924)	
R&D Intensity (%)		-1.1697	-0.32
		(-2.018)	(-1.277)
Plant Specific Factors			
Externally-Owned Plant	-1.6122	30.3135	7.8209
	(-2.159)	(4.502)	(1.994)
Graduate Share of the Workforce (%)	0.32		
	(12.255)		
National Market Share (%)		-0.953	
		(-0.805)	
Plant Size (1993 Employment)		0.0081	0.0052
		(0.827)	(1.307)
Plant Size Squared (1993 Empl Squared)		-0.001	-0.0004
		(-0.690)	(-1.184)
Plant Undertaking In-House R&D		-19.6052	2.5793
		(-2.884)	(0.707)
Plant is Part of Larger Group		76.6262	5.3466
		(8.309)	(1.675)
Plant Has Formal R&D Department			5.8001
			(1.771)
Real Sales Growth 1991-93 (% pa)		-12.7163	5.7439
		(-0.764)	(0.789)
Industry Factors			
Tech Transfer Intensity (mean %)		1.3142	
		(4.977)	
Networking Intensity (mean %)			0.9585
			(5.275)
R&D Intensity (mean %)	0.4204		
	(5.047)		
Average Plant Size (1993 Employment)			0.0484
			(1.642)
Regional Factors			
Population Density (per km^2)		-0.0255	
		(-1.853)	
Relative GDP Per Capita (EU =100)	-0.0341	0.5039	-0.15
	(-0.661)	(0.691)	(-0.540)
Govt R&D Employment (%)	0.0264	0.2207	0.1488
	(0.845)	(0.656)	(0.946)
Graduate Share of Workforce (mean %)	-0.3179	0.7897	1.4944
	(-1.229)	(0.251)	(1.087)
R&D Intensity (mean %)	0.4649	-10.7637	-2.4308
	(0.932)	(-1.706)	(-0.905)
N	774	766	765
Log Likelihood	-2024.4	-1108.1	-1862.3

Notes and Sources

1. T-statistics are given in parentheses. Industry variables are sectoral averages of the factor intensities derived from the PDS at the 2-digit level within each country.

2. Regional variables relating to R&D intensity, the graduate share of the workforce, and the proportion of plants undertaking R&D and with an R&D department are regional averages of PDS data for NUTS 2 regions. Relative GDP per capita in 1991 compared to the EU average (%) also at the NUTS 2 level was taken from Regional Trends, 1994, Table 2.1. Population densities, also at the level of the NUTS 2 regions were constructed from data from the same source. Government R&D is the share of the labour force engaged in government R&D in 1993 and is taken from R&D Annual Statistics (Eurostat) 1996, Table 15b. Figures are on a head-count basis.

Table 3: Tobit Models of R&D, Networking and Technology Transfer Intensity in Germany

	Innovators Only		
	R&D	Technology Transfer	Networking
Constant	-5.4525	-153.521	-34.8367
	(-1.240)	(-1.913)	(-2.947)
Factor Intensities			
Technology Transfer Intensity (%)	-0.0265		-0.2403
	(-0.699)		(-3.454)
Networking Intensity (%)	0.0271	-0.6272	
	(0.830)	(-1.544)	
R&D Intensity (%)		0.1337	0.0748
		(0.187)	(0.691)
Plant Specific Factors			
Plant Size (1993 Employment)	0.0036	0.019	0.0115
	(2.222)	(0.885)	(2.909)
Plant Size Squared (1993 Empl. Squared)	-0.0008	-0.0051	-0.0018
	(-2.242)	(-1.066)	(-2.353)
Externally-Owned Plant	6.8785	12.6844	
	(1.745)	(0.422)	
Graduate Share of the Workforce (%)	0.4689	1.3992	0.187
	(9.096)	(2.416)	(1.784)
National Market Share (%)		-0.7329	-2.2888
		(-0.115)	(-2.160)
Plant Undertaking In-House R&D		-31.9902	3.8028
		(-2.325)	(1.784)
Plant Has Formal R&D Department		17.7025	-1.7436
		(1.314)	(-0.830)
Real Sales Growth 1991-93 (% pa)		-16.2814	0.9032
		(-0.859)	(1.090)
Plant is Part of Larger Group		58.8814	4.3951
		(4.519)	(1.990)
Industry Factors			
R&D Intensity (mean %)	0.7428	-0.9903	-0.5128
	(6.591)	(-0.660)	(-2.268)
Technology Transfer Intensity (mean %)	-0.2495	2.4449	
	(-2.528)	(2.526)	
Networking Intensity (mean %)	-0.0936	0.2789	1.3175
	(-1.233)	(0.303)	(9.412)
Average Plant Size (1993 Employment)		-0.0592	-0.0108
		(-1.102)	(-1.549)
Regional Factors			
Population Density (per km^2)	-0.0016	0.0175	
	(-1.376)	(1.037)	
Relative GDP Per Capita (EU=100)	-0.0141	0.1752	0.1014
	(-0.615)	(0.504)	(2.033)
Govt R&D Employment (%)	0.0211	-0.3906	-0.0724
	(0.913)	(-1.529)	(-1.933)
Plants With In-House R&D (%)		70.1727	13.4971
		(0.757)	(1.126)
Plants with Formal R&D Departments (%)	-3.8783	89.101	
	(-0.609)	(0.888)	
R&D Intensity (mean %)	0.5187	-3.517	
	(1.626)	(-0.623)	
Graduate Share of the Workforce (mean %)		-0.5745	0.9977
		(-0.096)	(1.648)
N	772	728	797
Log Likelihood	-2027.3	-390.0	-2166.8

Notes and Sources: See Table 2.

Table 4: Tobit Models of R&D, Networking and Technology Transfer Intensity in the Republic of Ireland

	Innovators Only		
	R&D	Technology Transfer	Networking
Constant	-2.3613	-51.3483	-13.1344
	(-1.486)	(-3.940)	(-2.340)
Factor Intensities			
Technology Transfer Intensity (%)	-0.0958		-0.3846
	(-4.277)		(-4.326)
Networking Intensity (%)	0.0067	-0.5687	
	(0.234)	(-2.013)	
R&D Intensity (%)		-2.7712	0.3044
		(-2.267)	(1.110)
Plant Specific Factors			
National Market Share (%)	-0.0964		0.6878
	(-0.686)		(1.298)
Externally-Owned Plant		57.2992	
		(5.904)	
Plant Size (1993 Employment)	-0.0088		0.0191
	(-1.843)		(0.907)
Plant Size Squared (1993 Empl. Squared)	0.0054		-0.0152
	(1.806)		(-1.046)
Graduate Share of the Workforce (%)	0.0923		0.1057
	(1.909)		(0.570)
Plant Undertaking In-House R&D		-4.2456	
		(-0.410)	
Real Sales Growth 1991-93 (% pa)		-34.3201	
		(-2.193)	
Plant is Part of Larger Group			10.5522
			(2.468)
Industry Factors			
R&D Intensity (mean %)	0.9857		
	(5.449)		
Technology Transfer Intensity (mean %)	0.0532	1.5975	0.2139
	(1.439)	(5.377)	(1.556)
Networking Intensity (mean %)	-0.0171	0.5062	1.1435
	(-0.312)	(0.982)	(5.888)
Average Plant Size (1993 Employment)	0.0288		-0.1225
	(1.486)		(-1.625)
N	286	253	270
Log Likelihood	-709.7	-430.9	-715.9

Notes and Sources: See Table 2.

Table 5: Tobit Equations For Innovation Intensity and Innovation Success

	Innovation Intensity			Innovation Success		
	UK	Germany	Ireland	UK	Germany	Ireland
Constant	0.2131	0.0886	0.218	-31.0786	-25.3361	-12.1501
		(3.66)	(6.67)	(-1.26)	(-5.08)	(-1.73)
Factor Intensities						
R&D Intensity (%)	0.0045	0.0104	0.002	0.4997	0.2089	0.4913
	(1.83)	(6.33)	(0.80)	(1.93)	(1.41)	(1.31)
Technology Transfer Intensity (%)	0.0004	0.0008	-0.0003	0.143	0.1232	0.17
	(0.63)	(0.91)	(-0.35)	(2.14)	(1.18)	(1.99)
Networking Intensity (%)	-0.0003	-0.0004	0.0004	0.1036	0.0797	0.1301
	(-0.58)	(-0.55)	(0.56)	(1.47)	(0.99)	(1.12)
R&D x Tech Transfer	-0.0001		0.0001	-0.0165		-0.0217
	(-0.95)		(0.89)	(-1.32)		(-1.21)
R&D x Networking	-0.0002	-0.0004				
	(-1.65)	(-3.92)				
Tech Transfer x Networking			-0.0001			
			(-0.94)			
Plant Specific Factors						
Plant Size (1993 Employment)	-0.0003	-0.0001	-0.0001	-0.003		
	(-4.96)	(-3.37)	(-1.19)	(-1.66)		
Plant Size (1993 Empl Squared)	0.0001	0.000				
	(3.50)	(2.76)				
Externally-Owned Plant	-0.0494		0.0421	3.2407	31.3354	8.4992
	(-1.72)		(1.02)	(0.92)	(2.91)	(1.76)
Graduate Share of the Workforce (%)	-0.001		-0.0018	0.3678	0.2948	0.0774

	(-0.84)		(-1.01)	(2.55)	(1.94)	(0.36)
Plant is Part of Larger Group		-0.0731	-0.1227		-7.3994	
		(-2.46)	(-2.93)		(-2.24)	
Plant Has Formal R&D Department				2.1298		8.7324
				(0.71)		(1.72)
Plant Undertaking In-House R&D				2.9243	7.3703	
				(0.86)	(2.96)	
Industry and Region Factors						
Industry Innovation Intensity	0.0266	0.1198	0.0956	0.6849	0.618	1.0733
	(1.39)	(4.57)	(1.89)	(8.46)	(9.19)	(9.70)
Regional Innovation Intensity	0.0004	0.2682		0.716	0.7565	
	(0.010)	(5.23)		(1.67)	(10.50)	
N	629	708	241	684	720	245
Log Likelihood	-18.9	-137.9	18.2	-3014.2	-3047.6	-1033.4
Combined Factor Effects (at means)						
R&D	0.0008	0.0056	0.004	0.309	0.209	0.111
Tech Transfer	-0.0005	-0.001	-0.002	0.104	0.08	0.13
Networking	-0.0007	-0.0004	-0.001	0.069	0.123	0.092

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