Innovation and Business Performance:

A Provisional Multi-Regional Analysis

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Abstract

Innovation is now widely understood as an evolutionary process, strongly conditioned by a firm's institutional, locational and market context. An innovation event (e.g. the introduction of a new product or process) represents the end of a process of knowledge sourcing, co-ordination and codification by a firm or partnership.
This paper provides a preliminary examination of the causal links in this process of knowledge sourcing, co-ordination and exploitation and their relationship to enhanced business performance. The paper represents the first analysis of a large-scale multi-regional dataset covering three UK regions, Ireland and two German regions.
The empirical focus of the paper is on the *knowledge production function* and the way in which the effectiveness of knowledge co-ordination is influenced by firms' managerial and organisational capabilities. The final link in the causal process relates to *knowledge exploitation* i.e. how enterprises' business performance is influenced by the co-ordination of knowledge inputs and the innovations which result from the process of knowledge production Knowledge sourcing through in-house R&D and through supply chain and non-supply chain collaboration are shown to be complementary and important in shaping firms' innovation. Innovation is then shown to be positively linked to turnover and employment growth. No such link is evident to profitability.

Innovation and Business Performance: A Provisional Multi-Regional Analysis

1. Introduction

Innovation is now widely understood as an evolutionary process, strongly conditioned by a firm's institutional, locational and market context (Nelson and Winter, 1982). An innovation event (e.g. the introduction of a new product or process), however, represents the end of a process of knowledge sourcing, co-ordination and codification by a firm or partnership. It also represents the beginning of a process of value added generation which, subject to market conditions, may result in an improvement in the performance of the innovating business and also perhaps - through spillovers- improvements in the performance of co-related or co-located firms. Following recent studies by Crepon et al., (1998), Loof and Heshmati (2000, 2001), and Love and Roper (2001), this paper provides a preliminary examination of the causal links in this process of knowledge sourcing, co-ordination and exploitation and their relationship to enhanced business performance.

The paper represents the first analysis of a large-scale multi-regional dataset covering three UK regions, Ireland and two German regions and focuses on three main research issues:

(a) How do firms assemble the bundle of knowledge necessary for innovation? What roles do in-house R&D, supply-chain collaboration and non-supply-chain collaboration play in firms' knowledge sourcing activities? How are these activities inter-related?

(b) How do the characteristics of the enterprise, including its own knowledge and managerial resources, shape organisations' ability to acquire and co-ordinate the knowledge necessary for innovation?

(c) How do the characteristics of the enterprise and its operating environment influence the organisations' ability to appropriate economic value from its knowledge base and innovation activity?

The focus of the paper is therefore on the *knowledge production function* and the way in which the effectiveness of knowledge co-ordination is influenced by firms' managerial and organisational capabilities (Griliches, 1992; Love and Roper, 1999). The final link in the causal process relates to *knowledge exploitation* i.e. how enterprises' business performance is influenced by the co-ordination of knowledge inputs and the innovations which result from the process of knowledge production (Geroski and Machin, 1992; Geroski et al., 1993). More broadly, the research takes account of the process of technological change embodied in literatures on regional and national innovation systems, in which knowledge sourcing, co-ordination and exploitation activities of firms may be influenced importantly by cultural norms, markets and the presence of co-located firms and other organisations (e.g. universities, government research laboratories). The approach adopted is therefore integrative, drawing on aspects of the management, economics and industrial organisation literatures relating to innovation, capabilities, and technological change.

Thus, in addition to the above literature on the knowledge production function, we are influenced by the literature on boundary spanning activities within innovation (Conway, 1995) and on dynamic capabilities (Teece et al., 1997). All of these are concerned with the ultimate question of how firms capture value from their own and others' knowledge assets.

Section 2 of the paper defines our conceptual model. Section 3 provides an overview of the study regions and describes our data sources. Section 4 reports the main empirical analysis and section 5 concludes with a summary and final remarks.

2. Conceptual Framework

Following Crepon et al. (1998) (CDM) and Loof et al. (2000, 2001) (LH) we define here a model which relates business performance to firms' level of innovation activity. Implicit in both the CDM and LH studies, however, is the implicit assumption that undertaking R&D provides a unique route through which a firm may acquire the knowledge on which to base its innovation activities[1]. This assumption is contradicted by much recent evidence, however, which stresses the importance for innovation of knowledge flows which span the boundaries of individual businesses creating 'extended enterprises' and providing the basis for competition between supply chains. At the level of the individual business too, inter-company networks (e.g. Oerlemans et al., 1998) and intra-group knowledge transfers (e.g. Love and Roper, 2001) (LR) have been shown to have positive effects on innovation outputs.

To take account of the alternative routes by which individual businesses can source the knowledge inputs for innovation we explicitly allow here for knowledge sourcing through R&D (RKS_i), innovation collaboration along the supply-chain ($SCKS_I$), for example with customers, suppliers etc. and innovation collaboration with firms and organisations outside the supply-chain ($XSCKS_i$), e.g. consultants, universities, and public or private research laboratories.

Following the general line of argument in the innovation production function literature stemming from Griliches (1989), firms will invest in knowledge sourcing for innovation only if the expected returns are positive, with the scale of any investment varying positively with the expected rate of return. Decision-theoretic models of the choice of research intensity by firms, for example Levin and Reiss (1984), therefore relate the intensity of knowledge sourcing activity to the expected post innovation margins, the structure of the industry within which the firm is operating, the market position of the firm itself, and a range of other firm and industry specific factors. This suggests that investments by firm i in knowledge sourcing through R&D (RKS_i), supply chain collaboration ($SCKS_I$) and non supply-chain collaboration ($XSCKS_i$) may be represented by equations of the form:

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1. Another possible interpretation of the structure of the CDM and LH models is that they regard R&D and networking activities as complimentary activities. While there is some evidence to this effect relating largely to the role of R&D in expanding firms absorptive capacity (e.g. Harabi, 1997) other evidence points to the possibility that networking may be a substitute for in-house R&D investments (e.g. Love and Roper, 2001).

$$RKS_i = \gamma_{10} + \gamma_{11}\pi_i^e + \gamma_{12}MPOS_i + \gamma_{13}RBASE_i + \gamma_{14}RIS_j + \gamma_{15}ITECH_k + \varepsilon_1$$
$$SCKS_i = \gamma_{20} + \gamma_{21}\pi_i^e + \gamma_{22}MPOS_i + \gamma_{23}RBASE_i + \gamma_{24}RIS_j + \gamma_{25}ITECHV_k + \varepsilon_2 \quad (1)$$
$$XSCKS_i = \gamma_{30} + \gamma_{22}\pi_i^e + \gamma_{32}MPOS_i + \gamma_{33}RBASE_i + \gamma_{34}RIS_j + \gamma_{35}ITECH_k + \varepsilon_3$$

where π^e_i is the expected level of post innovation returns, $MPOS_i$ is a group of variables representing the market position of the firm, $RBASE_i$ is a group of variables reflecting the strength of the firm's internal resource base, RIS_j is group of variables reflecting the strength of the regional innovation system within which the firm is located, and $ITECH_k$ is a series of indicators reflecting the character of the industry in which the firm is operating.

The inclusion of variables to represent the market position of the firm (i.e. MPOS) is intended to reflect issues of appropriation and potential Schumpeterian or monopoly effects related to plant size. CDM, for example, in their model for R&D investment, include measures of firms' market share and diversification. Indicators of business size (and size squared) are also included by CDM, LH and LR to reflect potential scale effects. The characteristics of the internal resource-base of the business are less well represented in CDM and LH, although both include a measure of the quality of firms' workforce. In their knowledge sourcing equations, LR also include measures relating to the nature of firms' production activities and the organisation of any R&D being undertaken in-house.

Other factors included in equation (1) reflect the industrial and regional context in which the firm is operating. In terms of the technological characteristics of the industry, for example, CDM include dummy variables to indicate whether technological change in each sector is characterised by demand pull or technology push and a series of industry dummy variables[2]. LH (2000) on the other hand use a technological classification (their INTE dummy) indicating whether the firm is operating in knowledge-intensive, labour intensive or capital-intensive industries. LR adopt a more explicitly empirical approach focusing on the organisation of production activity within the industry (i.e. concentration ratios, MES estimates) and the general level of knowledge sourcing activity in the industry. Other recent studies (e.g. LR Roper et al., 2001) have also suggested that the spatial context within which a firm is operating - i.e. the regional innovation system (e.g. Braczyk et al., 1998) may also have an important influence on its innovative capacity. CDM and LH (2000, 2001) use no spatially distinct variables in their analysis. LR, however, do indicate the importance of a range of spatially distinct agglomeration (e.g. population density) industrial composition (proportion of employment in high-tech sectors, size structure of local firms) and R&D investment variables (e.g. government and private R&D spending) for firms' knowledge sourcing activities.

Measuring the intensity of firms' knowledge sourcing through R&D is relatively straightforward with standard indicators (used by CD, LH and LR) measuring R&D

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2. These are derived by CDM from the 1990 French Innovation Survey and express whether in the opinions of the firms surveyed demand and technology factors had a 'weak', 'moderate', or 'strong' influence on its innovative activities over the preceding five years (CDM, p. 121).

employment (expenditure) relative to either total employment (turnover). Measuring the intensity of knowledge sourcing through firms' supply-chain and non supply-chain innovation linkages is more experimental, and here we follow LR (2001) who develop intensity scores for the extent of firms' external contacts. More specifically, Love and Roper (2001) construct an intensity score which is proportionate to the number of innovation activities where the firm is involved in outsourcing[3]. Here we adopt a similar approach constructing intensity scores for each firms' knowledge sourcing through supply-chain and non supply-chain collaboration based on the number of types of organisation with which the firm is undertaking collaborative innovation activity. For example, we identify six types of potential supply-chain partners (customers, suppliers, competitors, other group companies, joint ventures and ???) for companies undertaking innovation collaboration with three of these types of partner 'score' 50 per cent, firms collaborating with all six types of partner score 100 per cent.

If firms' expectations about post-innovation returns are rational, i.e. involve no systematic errors, and we regard

$$\pi_i = \beta_0 + \beta_1 MPOS_i + \beta_2 RBASE_i + \beta_3 ITECH_k + \eta_i \qquad (2)$$

We can substitute for expected post-innovation returns in equation (1) to obtain reduced form knowledge sourcing equations:

$$\begin{aligned} RKS_i &= \theta_{10} + \theta_{12} MPOS_i + \theta_{13} RBASE_i + \gamma_{14} RIS_j + \theta_{15} ITECH_k + \lambda_1 \\ SCKS_i &= \theta_{20} + \theta_{22} MPOS_i + \theta_{23} RBASE_i + \gamma_{24} RIS_j + \theta_{25} ITECH_k + \lambda_2 \qquad (3) \\ NSCKS_i &= \theta_{30} + \theta_{32} MPOS_i + \theta_{33} RBASE_i + \gamma_{34} RIS_j + \theta_{35} ITECH_k + \lambda_3 \end{aligned}$$

where: $\theta_{12}=\gamma_{12}+\gamma_{11}\beta_1$ and $\lambda_1=\varepsilon_1+\gamma_{11}\eta$ etc.

Knowledge sourced through R&D, supply-chain or non-supply chain collaboration will then be combined into a form which can be commercially exploited, i.e. innovation. Locational and industry-specific factors may also be important - along with the resource base of the firm - in determining the efficiency with which acquired knowledge is translated into commercially exploitable outputs or innovations ($INNOV_i$). The potential for such effects suggests a general form of innovation production function (Geroski, 1990; Harris and Trainor, 1995):

$$\begin{aligned} INNOV_i &= \varphi_0 + \varphi_1 RD_i + \varphi_2 XNET_i + \varphi_3 INET_i + \chi_1 MPOS \\ &+ \chi_2 RBASE + \chi_3 RIS + \chi_4 ITECH + \mu_i \end{aligned} \qquad (4)$$

where we allow for the possibility of regional (RIS) (Audretsch and Feldman, 1996) and industrial efficiency (ITECH) effects on as well as plant specific variables (MPOS, RBASE).

Different measures of the outputs from the innovation process are possible reflecting the potential technological, commercial and organisational outcomes. The percentage of sales derived from innovative products (used by LH, CDM and LR), for example,

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3. LR (2001) consider firms' networking during seven activities which form part of the product development process: the identification of new or improved products; prototype development; final product development; product testing; production engineering; market research and marketing strategy.

reflects the commercial success of firms' innovation activity but provides little insight into the technological complexity or 'quality' of the developments made. Patent applications as, used by CDM (1998), arguably provides a more robust indicator of the technological integrity of firms' innovation activity but gives little insight into the commercial value of any developments. Another measure - innovation intensity or product changes per employee - used by LR provides a more direct indicator of the volume of outputs from firms' innovation activity but may reflect both incremental changes and radical product developments and, like patents, provides little insight into the commercial success of firms' innovation activity.

The final element of the model describes the relationship between innovation and business performance, and takes the form of a standard production function augmented with the innovation indicator. Depending on the performance measure being considered we also allow for possible links to the firm's market position and internal resource base. CDM, for example, include the skill composition of the business which they argue reflects the differences in the efficiency of skilled relative to unskilled labour (p.123). That is, business performance (BPERFi) is given by:

$$BPERF_i = \lambda_0 + \lambda_1 INNOV_i + \lambda_2 MPOS_i + \lambda_3 RBASE_i + \tau_i \qquad (5)$$

The emphasis in the CDM and LH studies is on labour productivity (value added per employee) and its growth.

The complete model to be estimated then consists of the recursive system of equations (3), (4) and (5).

3. Study Regions and Data Sources

The study regions were chosen to highlight core-periphery differences within the EU, and to illustrate the impact of different types of RIS (Figures 2 and 3). Bavaria and Baden-Württemberg are both within the ‘core’ group of the EU regions, with GDP per capita consistently above the EU average (Table 1). Northern Ireland, the Republic of Ireland and Scotland had GDP per capita significantly below the EU average in 1990-1991 but have since experienced very different subsequent growth profiles. In Northern Ireland, GDP per capita has continued to lag 20-25 per cent below the EU average while dramatic economic growth rates in the Republic of Ireland have seen GDP per capita rise sharply. Indeed, by 1996, GDP per capita in the Republic of Ireland was 96 per cent of the EU average, compared to only 80 per cent in Northern Ireland (Table 1)[4]. Similar patterns are evident in unemployment rates with Baden-Württemberg and Bavaria having consistently less unemployment than the EU

4. Some care is necessary in interpreting these GDP figures for the Republic of Ireland due to the importance of profits repatriated by externally-owned companies. In 1996, this meant that GNP at market prices was only 88.8 per cent of GDP (Source: CSO, Table 3, NIE Dept of Finance). In 1990 the same figure was 89.7 per cent. In other words while the GDP figures for the Republic of Ireland given in Figure 1 overestimate the average level of per capita income in the Republic of Ireland the growth profile from 1991 onwards does give a realistic impression of welfare changes.

average. In Northern Ireland and the Republic of Ireland, unemployment rates were above the EU average until the mid-1990s (Figure 5), but have fallen more recently reaching 8-9 per cent by 1998 (Table 1).

Some other contrasts between the study regions may also be important in terms of their impact on regions' innovation potential. First, higher levels of per capita income in Baden-Württemberg and Bavaria may mean that firms in these regions face a local demand for higher quality, more sophisticated and more innovative products than firms in Northern Ireland and the Republic of Ireland (Gudgin, 1995). Secondly, population densities, which have been positively linked to higher rates of innovative activity particularly in high-tech industries (e.g. Frenkel and Shefer, 1998), are notably higher in the two German regions (Table 1). Thirdly, in 1996, both of the German regions had higher levels of R&D investment and patent applications per capita than Northern Ireland or the Republic of Ireland (Table 2). In terms of R&D spending the most significant differences exist in the business and government sectors, where R&D expenditure as a percentage of GDP in the two German regions was double that in Ireland. R&D spending by higher education was more evenly spread across the study regions at 0.35-0.56 per cent of GDP[5].

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5. Note that because of the differences in GDP per capita noted earlier these comparisons tend to underestimate the absolute shortfall between the Irish and German regions in R&D spending. For example, total R&D spending in Baden-Württemberg was 1.76 per cent of Baden-Württemberg GDP in 1996. Allowing for the difference in per capita GDP, an equal absolute level of spending per capita in Northern Ireland would have required an investment of 2.7 per cent of Northern Ireland GDP.
6. These are derived by CDM from the 1990 French Innovation Survey and express whether in the opinions of the firms surveyed demand and technology factors had a 'weak', 'moderate', or 'strong' influence on its innovative activities over the preceding five years (CDM, p. 121).
7. LR (2001) consider firms' networking during seven activities which form part of the product development process: the identification of new or improved products; prototype development; final product development; product testing; production engineering; market research and marketing strategy.
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Fourthly, important differences exist between the structure and development of the regional innovation systems of the study regions. In the Republic of Ireland, for example, as the low level of public investment in R&D suggests "The attention to R&D in the public sector and universities in the Republic of Ireland still lags far behind other EU and OCED countries, and the R&D innovation system relies heavily on the private business sector, especially multinational corporation inward investors" (NIEC, 1999, p. 74). In Northern Ireland, the imbalance is instead towards the dominance of local R&D by the public sector and higher education with relatively low levels of R&D investment by locally-based businesses. Hence: "Imbalance in the Northern Ireland system lies in the dominance of public-sector R&D capabilities in Government and the lack of research institutions outside government and the universities" (NIEC, 1999, p. 125). In contrast, both Bavaria and Baden-Württemberg benefit from the fact that Germany is a 'highly industrialised country with a well-developed innovative infrastructure' (Grupp et al., 1998). Baden-Württemberg, in particular, is often cited as having a well developed institutional infrastructure for innovation alongside a range of internationally competitive businesses (Cooke, 1997; Heidenreich and Krauss, 1998). Particular importance is attributed to technology centres such as those in Karlsrhur and Heidelberg (e.g. Hassink, 1993), the technology transfer activities of the Steinbeis-Stiftung network (e.g. Grotz and Braun, 1997; Heidenreich and Krauss, 1998) and the education and training systems (Braczyk, Cooke and Heidenreich, 1998).

South East England, which excludes London, has a total population of 4.8m, with the highest population density of any UK region outside the capital. GDP per capita is marginally above the EU average with a positive unemployment rate influenced by rapid service sector employment growth during the 1990s (Table 1). In technological terms, the South East enjoys a unique position within the UK regional hierarchy playing host to a disproportionately large number of company headquarters and R&D units. This is reflected in a level of patent applications per employee well in excess of the UK average (Table 2). In more general terms, however, levels of R&D spending in the region by both businesses, government and higher education are broadly in line with the UK average, although notably higher than the other UK study regions (Table 2).

In line with other regions in England, the South East - through the development of the network of Regional Development Agencies - has recently been given an increased degree of autonomy in terms of some aspects of industrial and business development. Debate continues over the likely effectiveness of these initiatives give the limited budgets of the RDAs and their policy competencies. In the South-East as elsewhere, however, innovation promotion has been seen as a priority by the South East England Development Agency. Other initiatives have also been also introduced in the English regions designed to enhance manufacturing competencies. One example is the network of Centres of Manufacturing Excellence which were launched in 2001 in partnership between the RDA and Small Business Service. The aim of the initiative is to create a virtual Centre with the resources to facilitate better co-ordination and networking within the local regional innovation system and to assist firms with accessing support for their innovation activities.

Northern Ireland is the smallest of the study regions having a 1996 population of 1.66m, and average income levels consistently 20-25 per cent below the EU average

(Table 1). The recent economic history of the region is one of declining traditional industries in the manufacturing sector (particularly textiles and heavy engineering) and a growing dependence on public and private service sector activity. Unlike the Republic of Ireland, inward investment to Northern Ireland has been relatively limited in recent years and has been dominated by software, networked services and back office activity. As a result, the region's manufacturing sector is dominated by smaller firms and weakly embedded externally-owned plants (Crone and Roper, 2000).

The main institutional and policy frameworks operating in Northern Ireland reflect relatively closely those of other UK regions despite substantial regional autonomy in some areas of public spending, notably economic development. The result is that the Northern Ireland innovation system shares many of the weaknesses of that of the UK as a whole highlighted, for example, by Walker (1993). Knowledge generation and sourcing in Northern Ireland is undertaken primarily by larger private sector manufacturing companies and by the region's two universities, although R&D spending by higher education in Northern Ireland is below that in each of the other study regions (Table 2).

Republic of Ireland - Largely as a result of the expansion of the externally-owned, high-tech sector, the Republic of Ireland has achieved spectacular national growth rates throughout the 1990s, earning the country its 'Celtic Tiger' nickname (Roper and Frenkel, 2000). The foundation for recent rapid growth was, however, laid in earlier decades as Ireland attracted substantial inward investment particularly from the US. By 1998, the cumulative effects of FDI into Ireland meant that inward investment accounted for 44.1 per cent of manufacturing employment, 68.4 per cent of net output (i.e. value added) and 87.7 per cent of exports (Ruane and Gorg, 1997). The same cumulative effect is also evident in the fact that the top 20 companies in the Irish electronics sector includes only two Irish firms (Roper and Frenkel, 2000).

Since the mid-1990s substantial efforts have been made to develop research capabilities and infrastructure within the Republic of Ireland and to set national priorities for development. EU Structural Funds were used, for example, to support collaborative programmes of research (the Programmes in Advanced Technologies or PATs) which established research institutes and centres of excellence in biotechnology, advanced manufacturing, opto-electronics, materials technology, software, telecommunications, and power electronics (NIEC, 1999, p. 71). More recently (March 2000) a £560m Technology Foresight Fund was launched.

Bavaria - Although the largest of the study regions in terms of total population, overall population density in Bavaria is well below that in Baden-Württemberg reflecting the rural nature of much of Bavaria (Table 1). Like Baden-Württemberg, however, Bavaria has maintained income levels well above the EU average throughout the 1990s, benefiting from the opening up of Eastern Europe (Jones and Wild, 1994). Unlike Baden-Württemberg, however, Bavaria has a mixed industrial structure with significant mechanical engineering, aerospace, automotive and electronic engineering sectors. Another feature of Bavarian industry is the prevalence of widely dispersed small- to medium-sized manufacturing plants. The average size of establishment in 1990 was 70.2 workers compared to a West German average of 153.7 (Jones and Wild, 1994).

The RIS of Bavaria has attracted substantially less attention than that of its neighbour Baden-Württemberg, however, Bavaria comes second overall in Germany, in patent intensity per 1000 employees in 1996 (see Blind and Grupp, 1999) and has comparable levels of R&D spending (Table 2). The geographically and sectoral dispersion of Bavarian industry, and the importance of small to medium enterprises, poses particular problems for innovation and technology transfer. During the 1990s, a network of state-backed technology transfer and venture capital companies were set up to compliment long-established research industry and university based research centres. For example, the Bavarian Innovation and Technology Transfer Company, a public limited company established in1995, was tasked with promoting partnership between firms and knowledge generating institutions, and special support is available for high-risk R&D projects undertaken by small and medium firms. Resources for these – and some other similar initiatives – have been derived from the proceeds of privatisation.

Scotland is the largest of the UK study regions in terms of population at just over 5.1m. Its industrial history mirrors that of Northern Ireland although recent inward investments - particularly in electronics manufacturing and finance - have done more to offset the decline in traditional industrial sectors. Scotland is also, of course, a major tourist and financial services centre unlike Northern Ireland. As a result GDP per capita in Scotland is close to the EU average (Table 1), although historically Scotland has had relatively high unemployment rates.

In terms of R&D spending, Scotland lags well behind the UK average in terms of spending by business and government but has higher than average spending by higher education. This reflects the strength of the Scottish educational system and in particularly the prominence of the Scottish university system. Previous studies have suggested that the deficit in terms of business R&D spend in Scotland relative to the rest of the UK is also evident in innovation activity (Love and Ashcroft, 1995). A key element of industrial policy in Scotland over the last few years has been a cluster based strategy designed to increase local sourcing, strengthen local supply-chains and attract inward investment in areas where Scotland already has an established supplier base.

Baden-Württemberg is the most densely populated of the study-regions and 'has, for the past twenty-five years, been seen as a model economy. At the heart of that achievement appeared to be a factor that increasingly explains competitive advantage: that is, the capacity to innovate" (Cooke, 1997). The region has been described as a "industrial district with intensive intra-regional linkages between suppliers and customers and between small and large firms with a dominant engineering base and a wide variety of different policy measures especially favouring SMEs in the innovation process" (Sternberg, 1999). Grupp et al. (1998) also suggest that Baden-Württemberg's R&D performers are particularly strong in the machinery cluster and therein in transport, engines and machine tools.

Despite these positive features, Grotz and Braun (1997) argue that the Baden-Württemberg region lacks most of the typical features of a mature industrial district: "in particular … levels of inter-firm co-operation in Baden-Württemberg are by no means above average" (Braczyk, Cooke & Heidenreich, 1998). Cooke (1997), and more recently Heidenreich and Krauss (1998), also stress the weakness of Baden-

Württemberg firms in semi-conductors, computers and IT communication technologies, biotechnology and some new materials. "The large question mark hovering over Baden-Württemberg's future is whether the regional innovation system put in place so carefully in the last twenty-five years is adequate to the future growth industries of informatics, telematics, multimedia, environmental technologies, biotechnology and financial services" (Cooke, 1997).

Data on innovation and business performance for the six regions is taken from a series of comparable postal surveys undertaken in 1999-2000 and relating to innovation activity over the 1996-99 (three-year) period. The original survey instrument was developed for the Irish regions and adapted for use in the other study regions (see Roper and Anderson, 2000). In each case the target population was manufacturing plants with more than 20 employees with sample responses weighted to give regionally representative results. In addition to data on their innovation activities, plants also provided information on the use of a range of IT and organisational techniques, barriers to innovation activity and a range of accounting measures. The latter group of variables are particularly important in the current context as they allow us to develop a range of indicators of business performance including measures of productivity (value added per employee) and an indicator of plants' gross profit margins.

Table 3 summarises some of the measures which form the focus of the empirical analysis to follow. In terms of knowledge sourcing, R&D employees as a percentage of the workforce was highest in South East England and Scotland and lowest in Northern Ireland. Non-supply chain and supply-chain linkages, however, were more common in both the Irish regions than in either the mainland UK regions or the two German regions (Table 3). One clear possibility is that Irish plants were substituting knowledge sourcing through collaboration for knowledge sourcing through in-house R&D activity. In terms of innovation, the proportion of innovating plants (i.e. plants introducing a new or improved product during the previous three years) was highest in South East England (78 per cent) and lowest in Northern Ireland (62.8 per cent) and Baden-Württemberg (62.0 per cent). A broadly similar pattern is also evident in innovation success - i.e. the proportion of sales derived from innovative products - among the UK regions. Plants in Baden-Württemberg and Bavaria, however, had higher proportions of sales derived from innovative products than any UK regions (Table 3).

Two measures of business performance are also reported in Table 3. Value added per employee is a standard indicator of labour productivity and is measured in £000 pa in 1998 prices. Gross profit margin (%) is derived as total sales less the cost of materials, labour and capital investment. As expected labour productivity was markedly higher in the two German regions than in the UK regions, with Northern Ireland lagging someway behind other areas. Median gross margins were perhaps less predictable a priori but were highest in South East England and Baden-Württemberg. Again the median gross margin in Northern Ireland was markedly below that in the other study regions (Table 3).

4. Empirical Analysis

We divide the empirical analysis into three sections relating to the three elements of the model defined in section 2. We focus initially on plants' knowledge sourcing activities, examining the determinants of R&D intensity and the extent of plants supply chain and non supply chain knowledge sourcing activities. Section 4.2 then considers the determinants of plants' innovation success and section 4.3 looks at the link between innovation and business performance.

4.1 Knowledge Sourcing

R&D intensity and the two indicators of the extent of plants' innovation collaboration are defined as percentages and Tobit estimation is therefore the relevant technique. Table 3 gives some preliminary estimates of these relationships across the six regions where the explanatory variables are included in the model if - in at least one of the three models - they have a t-statistic in excess of one. The first point of interest with the models is the sign and significance of the other knowledge sourcing activities. This gives an indication of the substitute (negative) or complementary (positive) relationship between the different types of knowledge sourcing activity. Our results emphasise complementarity although the strength of this relationship is not uniform between the three knowledge sourcing activities (Table 4). In particular, we find that plants engaged in non-supply chain collaboration were also much more likely to be engaged in supply-chain collaboration. Both were only weakly linked to R&D intensity. R&D intensity, however, was more likely among plants undertaking supply-chain collaboration.

Other aspects of these initial knowledge sourcing equations are less well defined with little consistency evident between the indicators which proved important. In terms of the impact of market position on R&D intensity, for example, older plants and those identifying significant barriers to innovation because of low rates of return were more likely to be undertaking R&D. Neither effect proved important for either supply chain or non supply chain collaboration. Perhaps most surprising, however, was the weakness of variables linked to both relative and absolute plant size. Regional factors also proved difficult to identify with any precision with little clear link between levels of regional R&D (in any sector) and plants' knowledge sourcing activities.

At this stage perhaps the clearest result from the knowledge sourcing equations is therefore the relatively strong complementarity between knowledge sourcing activities. The implication being the type of positive externalities envisaged in much of the endogenous growth theory literature.

4.2 Innovation Success

In the conceptual model defined above (section 2), innovations (new or improved products) are the result of an innovation production function having the knowledge sourcing activities as the inputs (i.e. equation 4). In the multi-regional database innovation success is defined in terms of the percentage of sales derived from products newly introduced or updated over the previous 3 years. Tobit is therefore again the relevant estimator and two initial estimates of the innovation production function are given in Table 5. Key interest in the relationship focuses on the significance of the knowledge sourcing activities for innovation success and whether market or resource based factors are more important in determining the efficiency with which plants' innovation inputs are translated into innovation outputs.

Of the knowledge sourcing activities supply chain collaboration proves most important to innovation success, although both R&D intensity and non-supply chain collaboration have a positive effect. This result is perhaps surprising - especially in terms of the impact of R&D on innovation success, however, other variables designed to reflect the organisation of R&D inputs rather than the scale of plants' R&D inputs do prove important. In terms of market position, we find little evidence of any 'learning' effect linked to plant vintage but it is clear that exporting plants are likely to be more successful innovators (Table 5). Plants producing smaller batches also tend to be more 'successful' innovators as do those identifying risk as an important barrier to their innovation activities.

A range of indicators of plants' resource base also prove important in determining innovation success. Workforce quality, for example, proves important, with the proportion of the workforce with no qualifications having a negative impact on innovation success. Likewise, the proportion of graduates in the workforce proves positive, albeit insignificant. The presence of an R&D department in the enterprise, and relevant R&D elsewhere in the group, also prove positive for innovation success as does the presence within the enterprise of integrated IT usage and a strong quality orientation (see Annex 1). Resource barriers prove less significant, although the (negative) sign pattern expected in terms of a lack of technical information and attitudinal barriers are as expected. More surprising is the positive impact on innovation success of a lack of cash for innovation. This reflects the link identified earlier between successful innovation and the realisation of the riskiness of the activity. One possibility is simply that a realistic appreciation of the risks and investment costs of innovation is an important element in shaping successful innovation activity.

4.3 Business Performance

We consider here three indicators of business performance derived from the multi-regional database: gross profit margin (% of turnover), sales growth over the previous three years and employment growth over the same period. Table 6 gives OLS estimates of equation (6) for each of the three indicators. As before variables are left in these initial estimates if in one of the three equations they had a t-statistic greater than unity. The main interest in these regressions focuses on the strength of the innovation success indicator in the models and the relative impact of the market position and resource indicators on business performance.

The innovation success measure is positive and significant in the models for sales and employment growth but has a negative and insignificant effect on profit margins. In other words, while we can identify a positive 'growth' effect from innovation we are able to identify no significant 'profitability' effect. Some similar differences are also evident between the effects of market position on business growth and profitability. Business age, for example, was positively linked to profitability but had a strong negative association with both sales and employment growth (Table 6). Exporting also had a strong positive association with increased profit margins but no significant effect in either growth equation.

Indicators of plants' resource base were generally only weakly defined in the performance models. The variables divided, however, into those having uniformly positive or negative effects on margins and growth and those having differential effects on each dimension of performance. Among the more significant uniform effects were workforce quality and having an R&D department in the plant, both of which contributed positively to both profit margins and sales and employment growth. Differential effects were noted, however, for quality orientation which had a positive effect on growth and a negative effect on margins and group R&D and employment (plant size) which were associated with positive effects on margins but negative growth effects.

5. Summary and Discussion

The focus of the initial analysis outlined here has been the process of knowledge sourcing, combination and exploitation which takes place as firms collaborate, innovate and market new products. Our analysis has highlighted the potential importance of both in house R&D activity and supply chain and non-supply chain collaboration as knowledge sourcing strategies for innovation. Moreover, the estimation suggests the strong complementarity between - at least - supply chain and non-supply chain innovation collaboration. Other determinants of plants' knowledge sourcing strategies are more difficult to identify with our initial analysis suggesting a complex of regional, resource based and market position factors.

In terms of the innovation production function, our analysis suggests the potentially important role of both R&D and external knowledge sourcing as inputs. The efficiency with which these inputs are then combined to produce innovations depends on both the market situation of the enterprise and its internal capabilities. We find little evidence, however, of any learning effects with no clear relationship evident between plant vintage and innovation outputs. Resource indicators such as workforce quality and the presence of an in-house R&D department, however, do prove important as does the presence within the enterprise of integrated IT usage and a strong quality orientation.

The final stage in the causal chain examined here is the link between innovation success and business performance, measured by profitability and business growth. Here our results are most satisfying in terms of business growth with strong positive links evident to innovation success. A statistically weaker and negative relationship is identified between profit margins and innovation success. This pattern of differential profitability and growth effects is reflected in other market position and resource indicators and is found in other studies of the determinants of business performance (e.g. Roper, 2000). One clear strategic implication is that the value of investing in innovation (or other internal capabilities) depends strongly on the strategic aspirations of the business. On the basis of our results in particular innovation represents a valid investment only if a business is seeking to grow rather than increase its profit margins.

The analysis reported here represents a somewhat cursory 'first-cut' through the multi-regional database. The results reported must therefore be treated with some caution. Future analyses will seek to broaden the range of innovation and business performance indicators considered and to undertake a more robust testing programme of any estimation results. In particular, this will need to take account the statistical issues of selectivity and simultaneity highlighted by Crepon et al. (1998). The approach adopted by Crepon et al. (1998) clearly has substantial potential, however, and may ultimately produce new systemic insights into the different processes which generate innovation in the study regions.

Table 1: Basic Regional Indicators

	Population 1996 000s	Population Density 1996 Persons/km^2	GDP per capita 1995-97 (EU15=100)	Unemployment rate April 1998 %
Baden-Württemberg	10346.9	289.4	124	6.0
Bayern	12018.7	170.4	127	5.7
Republic of Ireland	3626.1	51.6	96	7.9
London	7074.3	4466.9	143	8.1
South East	4841.5	413.1	104	4.1
Scotland	5128.0	65.6	96	7.3
Northern Ireland	1663.3	117.5	80	8.8
Memo Items:				
EU15	*373606.9*	*117.1*	*100*	*10.1*
Federal Republic of Germany	*81914.8*	*229.4*	*110*	*9.8*
United Kingdom	*58801.5*	*241.2*	*99*	*6.2*

Note: GDP per capita figures were originally in ECU per capita and expressed as a percentage of the EU15.

Source: Statistics in focus, Eurostat.

Table 2: R&D Expenditure and Patent Applications for the Study Regions

	Patent applications per capita 1996	R&D Expenditure as % of GDP in 1996			
		Business Sector	Government Sector	Higher Education	Total
Baden-Württemberg	327.55	1.00	0.34	0.42	1.76
Bavaria	270.91	1.04	0.22	0.34	1.60
Republic of Ireland	39.38	0.64	0.10	0.56	1.30
South East	132.77	1.13	0.34	0.42	1.89
Scotland	58.27	0.57	0.26	0.55	1.38
Northern Ireland	16.05	0.48	0.14	0.34	0.96
Memo Items:					
Federal Republic of Germany	*181.47*	*0.83*	*0.25*	*0.42*	*1.50*
United Kingdom	*82.25*	*1.27*	*0.28*	*0.38*	*1.93*

Source: Statistics in Focus, Eurostat

Table 3: Key Innovation and Business Performance Indicators: By Region

	Northern Ireland	Republic of Ireland	Scotland	South East England	Baden-Württemberg	Bavaria
Number of observations	336	552	333	169	271	336
A. Knowledge Sourcing						
R&D Percentage of Workforce (%,mean)	1.9	2.1	3.8	3.6	2.5	2.6
Non supply-chain Innovation Collaboration (%, mean)	12.218	15.970	9.545	9.305	8.569	8.650
Supply chain Innovation Collaboration (%, mean)	20.5	24.1	17.3	21.4	12.2	14.9
B. Innovation Indicators						
Plants introducing new products (%)	62.8	67.3	64.4	78.0	62.0	72.0
Innovation Products as % of sales (mean)	29.9	28.7	31.0	34.9	37.5	40.5
C. Indicators of Business Performance						
Value added per employee (£000, mean)	28.27	45. 99	39.83	44.15	57.76	82.07
Gross profit margin (%, median)	16.5	21.2	21.7	25.2	23.7	19.4

Source: Multi-regional Database

Table 4: Tobit Models of Knowledge Sourcing Activities - Six-Region Models

	R&D Intensity		Supply Chain Collaboration		Non-Supply Chain Collaboration	
	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio
Constant	-10.529	-2.942	-32.001	-1.888	-65.042	-2.937
R&D Intensity			0.118	1.081	0.087	0.704
Supply Chain Collaboration	0.031	2.357			1.278	17.093
Non Supply Chain Collaboration	0.008	0.567	0.979	17.392		
Market Position						
Plant Vintage (years)	0.013	1.720	-0.040	-1.098	0.036	0.802
Part of Multi-Plant Group	-0.358	-0.549	12.012	3.906	-3.377	-0.855
Production Mainly One Offs	-0.457	-0.640	-4.938	-1.425	-0.950	-0.218
Production Mainly Small Batches	1.236	2.140	-0.919	-0.334	4.997	1.438
Important Barriers: Risk	0.074	0.114	6.031	1.971	0.615	0.162
Important Barriers: Returns	1.071	1.848	0.898	0.325	-3.428	-0.980
Important Barriers: Partners	-1.172	-1.139	-3.447	-0.711	5.627	0.965
Plant is Exporting	0.011	1.063	-0.074	-1.531	0.104	1.738
Employment/Median Emp	-0.089	-1.040	0.377	0.917	-0.295	-0.589
Employment in 1998	0.001	0.210	0.002	0.134	0.016	1.155
Employment Squared	0.000	-0.316	-0.002	-0.706	-0.007	-1.665
Resource Base						
Workforce with Degree (%)	0.097	3.809	0.166	1.318	-0.041	-0.259
Workforce with No Qual. (%)	-0.023	-1.851	0.085	1.400	-0.171	-2.220
R&D Department in Plant	7.442	11.745	4.437	1.457	15.896	4.276
R&D in Group	-0.394	-0.621	11.152	3.804	12.676	3.497
Integrated IT Cluster	0.863	1.304	2.269	0.729	2.973	0.746
Quality Oriented Firm	0.644	1.039	6.854	2.357	-3.298	-0.895
Resource Barriers: Attitudes	-1.199	-1.289	2.073	0.481	2.919	0.548
Resource Barriers: Technology	-0.857	-1.107	0.004	0.001	4.464	1.010
Regional Indicators						
HERD per person (EU = 1.00)	0.035	0.776	-0.046	-0.216	-0.304	-1.104
GERD per person (EU = 1.00)	0.076	1.064	-0.080	-0.235	0.413	0.961
BERD per person (EU = 1.00)	-0.026	-1.809	-0.020	-0.296	-0.046	-0.537
Supply Chain Collaboration (%)	0.432	2.915	0.910	1.275	-2.383	-2.514
Non-Supply Chain Collab. (%)	-0.340	-1.131	-1.193	-0.833	5.858	3.240
N	1043		1049		1070	
Log-L	-2245.8		-2663.2		-1918.9	

Note: Each model also included a set of nine industry dummy variables which are not reported. Details of the 'Integrated IT' and 'Quality Oriented Plant' variables are given in Annex 1.
Sources: Multi-Regional Database, Tables 1 and 2.

Table 5: Tobit Models of Innovation Success

Dependent Variable	Innovation Success		Innovation Success	
	Coeff.	t-ratio	Coeff.	t-ratio
Constant	5.039	0.808	6.224	1.125
Knowledge Sourcing Activities				
R&D Intensity	0.200	1.471	0.193	1.421
Non Supply Chain Collaboration	0.062	0.796	0.054	0.706
Supply Chain Collaboration	0.246	3.392	0.262	3.738
Market Position				
Plant Vintage (years)	0.024	0.648		
Production Mainly Small Batches	5.411	1.739	6.189	2.031
Important Barriers: Risk	6.406	1.845	5.718	1.675
Important Barriers: Partners	-4.826	-0.855		
Plant is Exporting	0.164	3.060	0.159	2.978
Resource Indicators				
Workforce with Degree (%)	0.219	1.466	0.136	0.950
Workforce with No Qual. (%)	-0.107	-1.940	-0.107	-2.047
R&D Department in Plant	18.459	5.347	18.789	5.531
R&D in Group	5.318	1.592	4.318	1.309
Integrated IT Cluster	6.425	1.824	6.554	1.893
Quality Oriented Firm	5.677	1.721	6.385	1.956
Resource Barriers: Technology	-6.596	-1.587	-6.901	-1.702
Resource Barriers: Attitudes n	-5.113	-1.020	-5.663	-1.139
Resource Barriers: Lack of Cash	8.270	2.405	7.945	2.401
n	996		1032	
Log-L	-3752.09		-3886.1	

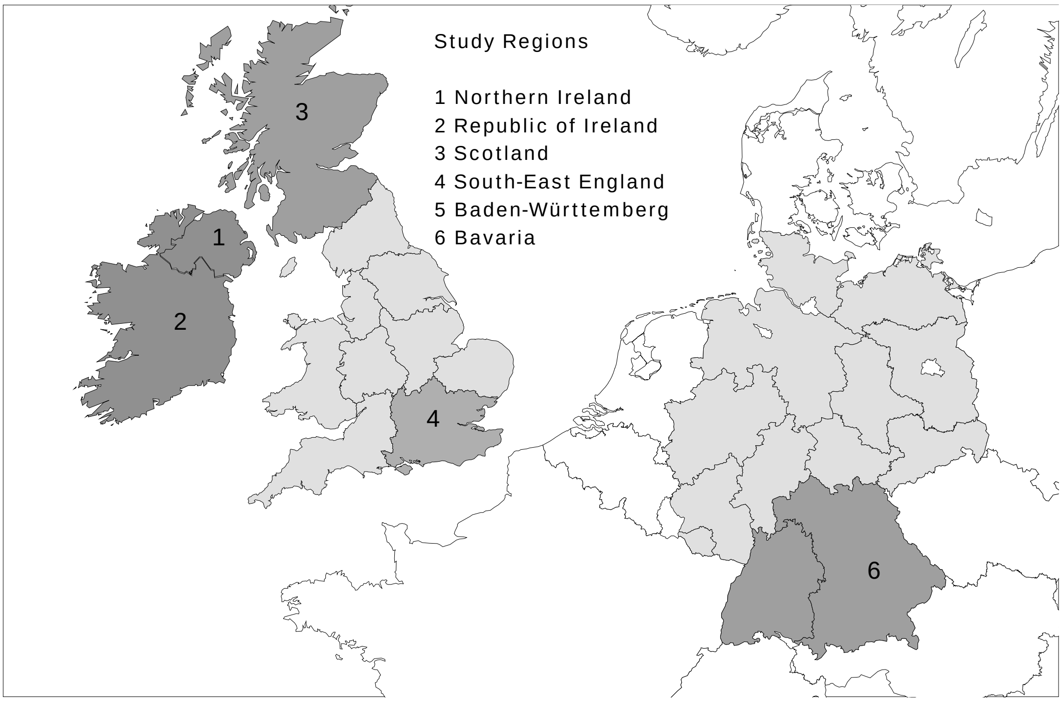
Note: Each model also included a set of nine industry dummy variables which are not reported. Details of the 'Integrated IT' and 'Quality Oriented Plant' variables are given in Annex 1.
Sources: Multi-Regional Database, Tables 1 and 2.

Table 6: OLS Regression Models of Business Performance

Variable	Profit Margin		Sales Growth		Employment Growth	
	Parameter	t-ratio	Parameter	t-ratio	Parameter	t-ratio
Constant	21.349	6.732	36.063	3.363	19.218	2.476
Innovation Success (Log)	-0.023	-1.068	0.276	3.827	0.207	3.974
Market Position						
Plant Vintage (years)	0.051	2.734	-0.315	-4.930	-0.254	-5.494
Part of Multi-Plant Group	1.924	1.230	-0.564	-0.106	-3.980	-1.036
Production Mainly One Offs	3.041	1.645	-5.906	-0.949	-1.586	-0.351
Production Mainly Cts. Production	2.110	1.316	4.398	0.808	1.654	0.418
Important Barriers: Risk	-2.159	-1.331	-8.091	-1.482	-4.426	-1.120
Important Barriers: Legislation	2.928	1.523	2.026	0.313	1.489	0.317
Important Barriers: Partners	0.869	0.340	16.012	1.865	12.248	1.949
Plant is Exporting	0.061	2.557	-0.032	-0.388	0.008	0.131
Resource Indicators						
Workforce with Degree (%)	0.089	1.114	0.270	1.006	0.090	0.464
Workforce with No Qual. (%)	-0.040	-1.464	-0.092	-0.995	0.045	0.670
Integrated IT Cluster	-1.653	-1.037	-2.246	-0.413	-1.333	-0.339
R&D Department in Plant	1.186	0.726	0.726	0.131	4.314	1.072
R&D in Group	0.621	0.405	-6.775	-1.308	-4.597	-1.224
Quality Oriented Firm	-2.432	-1.594	8.633	1.678	4.640	1.241
Resource Barriers: Technology	2.376	1.293	-7.032	-1.109	-0.988	-0.215
Resource Barriers: Attitudes	3.412	1.373	2.117	0.246	-0.150	-0.024
Resource Barriers: Lack of Cash	-2.254	-1.436	-2.215	-0.417	-5.530	-1.442
Employment	0.000	0.111	-0.015	-1.955	-0.015	-2.632
N	720		692		678	
Adjusted R-squared	0.034		0.080		0.086	
Std Error	17.70		58.90		42.21	
F(..) (ρ)	1.92 (0.034)		3.16 (0.00)		3.28 (0.00)	

Note: Each model also included a set of nine industry dummy variables which are not reported. Details of the 'Integrated IT' and 'Quality Oriented Plant' variables are given in Annex 1.
Sources: Multi-Regional Database, Tables 1 and 2.

Figure 1: Study Regions



Annex 1: Defining two cluster use variables

In the MPPDS we asked firms a series of questions relating to their use of a range of managerial and IT-based production systems. These original variables were then used to form two composite indicators of the internal resources of the business. The first of these related to the use of IT-based production techniques by the firm and covered CNC, CAD, CAM, AMH, CIM and robotics. Three clusters of businesses were identified using the SPSS k-means cluster procedure. The results define three groups of firms; firms with *Integrated IT* across the range of design (i.e. CAD) and manufacturing functions; firms with *IT Production* systems but no computerised design capability; and, a third group with *Low IT Use* across both manufacturing and design functions.

Table A1: IT-based Production Clusters

Technique	Cluster 1 Integrated IT	Cluster 2 IT Production	Cluster 3 Low IT Use
No of ob.	1172	263	655
CNC	62.0	100.0	0.00
ROBOTICS	26.3	17.1	6.7
AMH	29.4	34.6	17.3
CAD	100.0	0.00	0.00
CAM	41.9	30.8	20.2
CIM	24.5	19.4	11.0

The second internal resource indicator is based on four variables designed to reflect firms' use of managerial systems: quality certification, total quality management, quality circles and just-in-time. Again three clusters were identified using the k-means cluster procedure in SPSS. The three clusters can be identified as follows: an *Informal Management* grouping with low adoption rates of each technique; a *Total Quality* group each of which has implemented a total quality management approach; and, a *Certified Quality* group which have some form of quality certification but not TQM.

Table A1.2: Management Systems Clusters

Technique	Cluster 1 Informal Management	Cluster 2 Total Quality	Cluster 3 Certified Quality
No of observations.	1466	345	279
Quality Certification	47.1	83.2	92.8
Total Quality Management	14.3	100.0	0.0
Quality Circles	2.2	62.0	50.5
Just-In-Time	6.5	78.3	76.7

Cluster membership by region and plant sizeband is summarised in Tables A1.3 and A1.4. By region, Integrated IT functions are most common in BW and weakest in the peripheral UK regions (Scotland, Northern Ireland). Membership of the Total Quality and Quality Certification clusters is also most common among plants in bw. In terms of plant size the pattern is very much what might have been expected a priori: larger plants are most likely to have integrated IT systems with membership of the Low IT Usage cluster most common among smaller firms. Informal Management is also more common among smaller plants.

Table A1.3: IT-Based Production and Managerial Clusters by Region

	NI	ROI	SC	SE	BW	BA
IT-Based Production Systems						
N	333	546	341	251	274	345
Integrated IT	50.5	57.1	49.0	57.0	68.2	56.5
Production IT	16.2	12.5	15.0	10.4	5.8	13.9
Low IT Usage	33.3	30.4	36.1	32.7	25.9	29.6
Managerial Systems						
N	338	541	341	251	274	345
Informal Management	83.1	68.9	70.7	78.1	53.3	66.4
Total Quality	10.7	18.1	17.3	13.9	24.5	14.5
Quality Certification	6.2	12.9	12.0	8.0	22.3	19.1

Table A1.4: IT-Based Production and Managerial Clusters by Employment Size-Band

	20-99	100-249	250+
IT-Based Production Systems			
N	949	463	411
Integrated IT	48.4	62.9	74.0
Production IT	14.9	10.6	8.3
Low IT Usage	36.8	26.6	17.8
Managerial Systems			
N	942	465	411
Informal Management	81.3	61.5	45.0
Total Quality	9.9	18.1	35.8
Quality Certification	8.8	20.4	19.2

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