HIGH TECHNOLOGY FIRM PERFORMANCE, INNOVATION, AND NETWORKS : AN EMPIRICAL ANALYSIS OF FIRMS IN SCOTTISH HIGH TECHNOLOGY CLUSTERS

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High Technology Firm Performance, Innovation, and Networks

- An Empirical Analysis of Firms in Scottish High Technology Clusters

By

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TO THE MEMORY OF MY LATE FATHER

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ABSTRACT

This thesis is an empirical analysis of the performance, innovation and networks of high technology firms. It is conducted at the micro-economic level, based on new empirical evidence by fieldwork methods, from the primary source data on firms in the five Scottish hi-tech clusters. The questionnaire design is cross-sectional, to which was added a time series element, and involves many unique features. It enabled the gathering of rich quantitative and qualitative data on all stages of the dynamic innovation process. The database was used in cross-sectional analysis of many key hypotheses in the hi-tech context, by robust econometric models of export, innovation (e.g. Schumpeterian hypothesis), and growth (e.g. Gibrat's Law of Proportionate Effect) performances. The hi-tech firm's networks, internationalisation and embeddeddness, are analysed using novel measures.

A structural simultaneous equations model is developed to explain the relationship between networks, innovation and performance, by establishing a link between the innovation input, the innovation output, and performance, based on the empirical knowledge production function model. The 2-stage, 4 equations model, (using Heckman's procedure) deals with both simultaneity and sample selection bias. Robust estimation techniques (I3SLS, Tobit) are used for estimation.

The results highlight the simultaneity and selectivity issue. The hi-tech firms with aggressive innovation strategies, international markets and global products, still find it vital to be embedded in local networks, which in turn raise their performance. Technology-push factors, research networks, knowledge spillovers from markets, and a firm's radical innovation attempts determine its innovation input intensity. Firms are unable to attain innovation success through innovation investments alone; integration of internal and external resources is important. The innovation sales intensity are not determined by innovation input, but by the demand-pull factors like customer networks, exporting, and market expansion strategies. This also applies to their export intensity. Lack of internal resources, capabilities, and government support are the major obstacles to commercialisation of innovation.

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DECLARATIONS

I, Vandana Ujjual, hereby certify that this thesis, which is approximately 78,974 words in length, has been written by me, that it is the record of work carried out by me and that it has not been submitted in any previous application for a higher degree.

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I was admitted as a research student in Sept. 2002 and as a candidate for the degree of PhD in Mar. 2008; the higher study for which this is a record was carried out in the University of St Andrews between 2003 and 2007.

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Chapter 1 An Overview

1.1 Introduction

This research is an extensive empirical analysis of the performance, innovation and networks of firms, using appropriate statistical and econometric methods. The main object of analysis in this thesis is Scottish high technology firms. The analysis is conducted at the micro-economic level, based on new empirical evidence from primary source data on firms in the five Scottish hi-tech clusters. The principal aim of this thesis is to unravel the complexity in the structure of the dynamic innovation process in hi-tech firms, by identifying its determinants, and how it impacts upon the firm's overall performance. Primarily, this research, by structural equations modelling, tries to explain the links between the various stages of the innovation process in hi-tech firms, and also how it determines performance, based on the empirical knowledge production function model, (Pakes & Griliches 1984; Oerlemans et al. 2001b).

This thesis is inspired by the emerging work which now analyses the casual relation between innovation and performance at firm level, not as being simply from innovation to performance, but as being two-way, using a simultaneous equations model approach, (Benavente 2006; Loof & Heshmati 2006; Klomp & van Leeuwen 2001). Principally, the applied econometric model developed in this research builds upon the conceptual ideas of what may be called the base model, the CDM model (Crepon et al. 1998). In doing so, it extends the CDM model in a major way. It explains the interaction between the different stages of innovation, networks and firm performance in a new simultaneous framework, in terms of a specification which corrects for both sample selection and simultaneity bias.

In this way, the traditional analysis of the link between R&D and productivity is extended (Mairesse & Sasseno 1991; Hall & Mairesse 1995). The thesis uses an economic framework that endogenizes innovation, in explaining the heterogeneity of firm performance, thus contributing to the growing 'new literature' on the link between innovation and performance. In a wider context, this study is one of the few to estimate the causal effects of innovation input on innovation output and of innovation output on firm performance. This is done for both manufacturing and service industries (Metcalfe & Miles 2000), using a new simultaneous equations framework. The firm-level data on which this modelling is based was not previously available, and is a unique empirical resource.

This thesis aims to provide an in-depth understanding of the performance, innovation and networks of hi-tech firms. Under this broad research objective, a number of aspects that are of significant interests to researchers in industry, policy, and academia are explored. These are as follows, where key literature is indicated under each heading:

- The performance of the SMEs in relation to large firms, (Rominj & Albaladejo 2002; Acs & Audretsch 1990; Arvantis 1997), (see chapter 7). Specifically, it empirically tests two key hypotheses in the hi-tech context:
    - i) The Schumpeterian hypothesis, with respect to the relationship between innovation and firm size, (Kohn & Scott 1982; Scherer 1965; Acs & Audretsch 1988; Cohen & Klepper 1996).
    - ii) The Gibrat's Law of Proportionate Effect, with respect to the growth of firms relative to size, (Dunne & Hughes 1994; Reid 2007).
- Insights into the extent of internationalisation in hi-tech firms, (Hollenstein 2005; Kohn 1997; Lu & Beamish 2001), versus the extent of their local embeddeddness, (Keeble et al. 1998; Lawson et al. 1998), (see Chapter 8).
- The investigation of the export performance of hi-tech firms. This is undertaken by analysing the impact of various firm-specific and external determinants on the export intensity, separately from the impact on the export decision, (Lefebvre & Lefebvre 2002; Roper & Love 2002), (see Chapter 8, sec. 8.6)
- Detailed examination of the intensity of the firm's external networks and also the relative importance of the different alliances in stimulating innovation, (Baum et al. 2000; Pittaway et al. 2004), (see Chapter 9 and 10). Novel measures are created to assess the hi-tech network intensity.
- The impact of technology-push and demand-pull factors, on innovation and performance in firms is analysed, by focussing on organisational innovation strategies (Prajago & Ahmed 2006); spillover from different sources (Jaffe et al. 1993; Acs et al. 1994); and local spillovers (Niosi 2000b; Zucker et al. 1998b; Powell et al. 2002), (see Chapter 10).
- The analysis of the effect of a firm's different external networks on its innovation input, innovation success, and its performance, are undertaken by controlling for the impact of knowledge spillovers from different sources (Cooke 2001b; Feldman 2001), and controlling for its internal innovation effort (Belderbos et al. 2004).

- A broad range of different indicators is devised to capture the dynamic innovation process of hi-tech firms (Rothwell 1994; Hagedoorn & Cloodt 2003; Kleinknecht 2000).

To develop the analytical models in this research, new work was also involved in creating the indicators of innovation activity and networks. Four of these are particularly important:

- Absorptive Capacity (Lenox & King 2004; Zahra & George 2002; Henderson & Cockburn 1998; Cohen & Levinthal 1990)
- Firms' internal resources (Freel 2003; Hadjimanolis 2000; Nelson 2000)
- Innovative Milieu (Camagni 1991; Aydalot & Keeble 1988)
- Alliance & Innovation (von Hippel 1998; Chesbrough 2003a, Oerlemans 2001)

Lastly, but not the least, the inspiration for this research comes from the emerging industrial policy in Scotland, which is mainly cluster-driven with a great emphasis on knowledge-based clusters (SE 1998, 2005). Scottish Enterprise (SE) sees clusters as a means to achieve competitiveness and success through many initiatives targeted on technology sectors, with an emphasis on networking, interdependence between different elements in the cluster, and synergies created by co-existence within and between technology clusters (Raines 2001; Brown 2000). In this policy setting, this thesis provides insights into Scottish hi-technology, by analysing the optoelectronics, microelectronics, life science, digital media and software clusters, all of which have a high degree concentration of hi-tech firms.

The aim of this chapter is to introduce important aspects of hi-tech firms in four sections, and to briefly survey the key issues dealt with in this research. Section 1.2 and 1.3 introduces the concepts of hi-technology and clusters, respectively. Section 1.4 introduces the different streams of literature on the theoretical concepts on innovative clusters, especially the idea of an Innovative Milieu. Section 1.5 briefly reviews the UK and Scotland policy approaches to clusters, especially as developed in the Scottish Enterprise hi-tech cluster approach. Section 1.6 details the thesis structure and format.

1.2 High Technology

High technology has captured a disproportionate share of the international spotlight in recent years, as businesses, investors and policy makers alike believe in their indispensable role for economic prosperity in the developed and developing nations. “High technology” (Kodama 1991) has become, to many, the "economic Holy Grail" of the twentieth century (Markusen et al. 1986). In the last two decades, several regions of the US and elsewhere have developed strong local economies based on fast-growing hi-tech industries. They are assumed to be a key source of innovative ideas, products, and processes that are essential to modernizing older industries, and to maintain technological and economic competitiveness. Their job-creating potential, their ability to be a major force in the revival of depressed regions, and their rapid expansion have all attracted state and local governments to hi-tech industries. There is no ambiguity about their general significance, but what is not clear is what constitutes hi-tech, and how it should be defined. Kodama (1991) has made important contributions to the arduous task of understanding the meaning of high technology. According to him the characteristics features of hi-tech industries are:

- Technological diversification for survival
- The targeting of R&D effort towards demand-side initiatives
- Simultaneous investment in different stages of technological trajectories
- High degree of product obsolescence due to rapid innovation cycle
- Invisible competitors
- The ratio of R&D to capital investment is usually greater than one
- Technological fusion, the combining of existing technologies in new ways.

Against the above background of positive economics and policy towards innovation a sample of firms was to be gathered for examination. The framework adopted for doing this typically used Standard Industry Classification (SIC) codes in UK, (Butchart 1987), and US (Thompson 1987). They were used, in combination with other sources, to identify the hi-tech firms to be used for this research. This is explained further in chapter 6.

1.3 Clusters

An aspect of the global shift to ‘the new economy’ is that policy makers in sub-national regions around the world are setting in place the infrastructure and mechanisms needed to support technology-intensive industrial development. Much of this recent, global interest in clusters was influenced by the work of Michael Porter (Competitive Advantage of Nations, 1990). Interest in the cluster concept has been apparent in the increasing support for cluster development internationally. This is evident in the strong policy interests shown by the European Commission, the OECD and UNIDO, as well as associations of regions interested in pursuing cluster development (Competitiveness Institute, the Italian and French clubs of industrial districts), (Raines 2001). This policy process, as applied to the Scottish economy, is integral to the analysis of this thesis. The significance of the strong clustering of firms, their inter-firm links, technological spillover and embeddedness, in the operation and evolution of firms in the knowledge-intensive sectors, serving global markets, are investigated.

There have been a variety of different definitions proposed for clusters, (Feser 1998). Porter defines clusters as ‘concentrations of interconnected companies and institutions in a particular field’ (Porter 1998, p. 78). Meanwhile, the Department of Trade and Industry (DTI), defines clusters as ‘a concentration of competing, collaborating and interdependent companies and institutions which are connected by a system of market and non-market links’, (DTI 1998, p.22). Scottish Enterprise (SE) define clusters as ‘customers, suppliers, competitors and other supporting institutions such as universities, colleges, research bodies, financial institutions and the utilities’ (SE 1998). These definitions are rather similar, and help to define a common point of reference.

However, the term cluster itself involves a degree of ambiguity. To illustrate, it has strong kinship to related concepts such as ‘Industrial Districts’ (Brusco 1986; Marshall 1920), ‘Regional Innovation Systems’ (Cooke 2001b; Cooke et al. 1997) and ‘Innovative Milieu’ (Cappello 1999; Camagni 1996, 1991; Aydalot 1986). Terms such as value chains and business networks are also sometimes used interchangeably with the term clusters. In the UK from a national perspective, clusters are seen as an effective way of promoting national economic competitiveness as a whole, through a process of regional or local specialisation (DTI 1998), whereas from a regional or local perspective, clusters are viewed generically as a process for stimulating regional economic development (Brown 2000). Thus it is seen that clusters have prompted a variety of distinct but overlapping approaches to spatial development, like increasing national competitive advantage, enhancing local small and medium sized enterprise’s competitiveness, and improving industry-research collaboration at different spatial levels (Boekholt & Thuriaux 1999; Metcalfe 1995).

1.4 Studies on Innovative clusters

There are a vast number of studies that are based on the different innovative clusters, in different regions. Examples include:

- The well-known Silicon Valley in California, Austin, Texas, and Boston's Route 128 in the USA (Saxenian 1994a, 1994b; Scott 1992);
- Cambridge in the UK (Segal, Quince, Wicksteed 2000, 1986; Athreye 2001; Keeble et al. 1999);
- The regions of Rhône-Alpes, Sophia Antipolis in France (Longhi 1999; Longhi & Quere1993);
- Baden-Wurttemberg in Germany (Herrigel 1993; Sternberg 1999; Staber 2001);
- Lombardy and NEC Districts in Italy (Brusco 1990);
- Catalonia in Spain (Keeble & Wilkinson 1999);
- 26 clusters set up under Japan's Technopolis Law of 1983, (Rosegrant & Lampe 1992; Dalum 1995).

On the basis of the case studies of these successful regions, several authors have attempted to explain the specific reasons for the success of each of them. Furthermore, some general concepts have been developed, and various mechanisms have been identified, that are seen as the causes for the success of those regions (Ketels 2003). These form the background to numerous empirical studies devoted to the analysis of innovative clusters. Those studies that most significantly contribute to spatial clustering of hi-tech firms are identified. The main concepts are those of:

- Marshall's Industrial Districts (Marshall 1920), driven by the agglomeration of highly innovative SMEs, where the transaction between firms are by sequential stages in supply chains. It is characterised by external economies of scale and the existence of sub-contracting out to competitors. There is emphasis on the 'Industrial Atmosphere', (Brusco 1986; Markusen 1996; Sabel & Zeillin 1985);
- Innovative Milieu, which emphasises mainly informal social relationships in a limited geographical area, a specific image and internal representation which enhances local innovative capability through synergy and a collective learning process, (Lawson & Lorenz 1999; Camagni 1995; Malliat 1995);
- Untraded Interdependencies (Stroper 1995) drawn from the 'technology trajectories' (Dosi 1985) and 'technology learning literature (Lundvall 1992), which explains agglomerations that cannot be accommodated with input-output based theory. It

involves technological spillover, labour-market characteristics and develops along certain trajectories;

- Regional Innovative Systems (Cooke 2001b; Cook et al. 1997; van Dijk & Pieter 1995).

A general shift can be seen in reviewing these concepts, from static to dynamic externalities. The shift in focus is away from input-output to consider less tangible relations. The local-dynamic elements are complemented by co-operative arrangements with firms outside the area. The literature helps to suggest that clusters involve a certain degree of proximity between its actors. This enables face-to-face networking, common labour markets and the diffusion of knowledge (particularly 'tacit' knowledge that is difficult to codify), all of which are indispensable to innovation and knowledge intensive, hi-tech firms (Audretsch & Feldman 1996; Audretsch & Stephan 1996; Jaffe et al. 1993; Dosi 1988). The close collaboration and trust between firms and related institutions helps to overcome market failure, to spread risk and to facilitate innovation and learning through collaboration, (Best 1990; Piore & Sabel 1984). Geographical concentration, said by some to be important to the development and reproduction of such relationships as trust, is strengthened by a local common identity and tradition, and by spatial proximity (Storper 2004, 1993; Freeman 1991). The successful establishment and growth of small technology-intensive firms is often argued to benefit from location within a geographical cluster, of such firms, due to the advantages of informal and formal networking, and information flows within such a complex (Keeble et al. 1998; Storper 1995; Aydalot & Keeble 1988).

1.4.1 Innovative Milieu

The Innovative Milieu concept is restricted to the hi-tech sector. The Milieu idea was developed in the mid-1980s by the French GREMI group and has been continually developed since then (Aydalot 1986; Aydalot & Keeble 1988; Maillat 1995; Camagni 1995). It is defined as a 'complex network of mainly informal social relationships on a limited geographical area, often determining a specific image and a specific internal representation and sense of belonging which enhances local innovative capability through synergy and collective learning process'. The approach emphasises the importance of linkages that are not simply concerned with material transfers and have a specific 'milieu image'. Its characteristics are a collective learning process (enhancing local creativity), capacity for innovation, and dynamic uncertainty reduction mechanisms. In many respects, a Milieu can support innovation. Thus, joint information acquisition and analysis ease the recognition of successful market and technology decisions (‘search function’), image campaigns increase market visibility for local businesses (‘signalling function’) and exchange processes (like those connected with the mobility of employees between firms) further the collective learning process (‘transcoding function’), (Sternberg 2000).

Networks as well as Milieu are not necessarily permanently innovative. They can age, and lose their ability to innovate, and in such cases a distinctive Milieu acts as a hindrance, which solidifies old behavioural trends and blocks the influence of new technological developments (‘entropic death’ (Grabher 1993b). Hence, the connection of regional with global networks is necessary (Camagni 1991). The integration of a region and its intra-regional network into international and global networks play an essential role in the continual renewal of such networks. A milieu does not necessarily have to be restricted to a region. However, spatial proximity significantly raises its effect owing to the spatial determination of numerous elements of a milieu (Cre´voisier & Maillat 1991). There are numerous empirical studies based on the Innovative Milieu concepts in different regions, South-east England (Rominj & Albaladejo 2002), West of England (Konsaldakapulos 2004), Oxford & Cambridge (Lawson et al. 1998), Cambridge (Garnsey 1993; Athreye 2001), Cambridge Phenomenon (Segal, Quince, Whittaker 1986, 2000), Southern California (Scott 1992) and Sophia-Antipolis (Longhi & Quere 1993). Drawing on this innovative milieu literature, characterised by geographical proximity, dynamic uncertainty reduction, informal relationships and collective learning process, this research aims thereby to analyse the hi-tech firm in Scotland.

1.5 Policy Approaches to Clusters in UK

Although the antecedents of the concept of clusters can be traced back to Alfred Marshall’s Principles of Economics (1890), where he spoke of industrial districts in Britan, the concept has recently gained a renewed policy emphasis worldwide. While Michael Porter’s earlier classic, ‘The Competitive Advantage of Nations’ (Porter 1990) covered the UK’s cluster structure in some detail, mentioning strengths in engines (aerospace), textiles, oil, consumer products (whisky, soaps and sweets), services (financial), trading and chemicals, his later work, ‘Clusters and the new economics of competition’ (Porter 1998), merely refers to cluster development initiatives in Scotland and Northern Ireland, and mentions specifically only confectionery in York in England. If the list of successful clusters mentioned in the literature, rarely include any references to British industries or localities, Scotland is an exception. Scotland has been at the forefront of clusters policy since the 1990s. The significant cluster initiatives by SE (Scottish Enterprise: established by the Enterprise and New Towns (Scotland) Act 1990), has attracted national and international attention. By contrast, clusters in Britain are perceived to be synonymous with the old Marshallian manufacturing industrial districts that may have been the bases of Britain's economic success in the 19th century, but which have since suffered long-term chronic decline, (DTI 2000a).

There has been renewed interest in clusters (in a modern sense) in the UK at national, regional and local level. The productivity gap between the UK and its major competitor nations like the US, France and Germany has been a major concern of the UK's domestic economic policy agenda through the 1990s and before, (Denyer & Neely 2004). Successive governments have explored various ways in which this productivity gap might be closed, with the current government focusing heavily on innovation (DTI 2003). At the national level, the publication of the Competitiveness White Paper in 1998 promoted the development of cluster approaches, (DTI 1998). The DTI has taken the government's clusters agenda further by commissioning a full mapping study of existing cluster-related activity in the UK (DTI 2000a), and forming a Clusters Policy Steering Committee, chaired by Lord Sainsbury which looked at the possibility for new policy initiatives. This was the first attempt to provide a nationwide 'audit' of what clusters existed, where they were and what the relevant policy issues were. At a regional level, the Regional Development Agencies (RDAs) has been incorporating cluster policies to their regional economic strategies in England. In Scotland, SE saw clustering as a means of increasing private sector dynamics to increase its share of GDP. At a local level, a number of local authorities are encouraging cluster-based approaches as part of their local economic development strategies for some time, although they have not always been explicitly identified as such.

There are a number of studies on clusters in the UK: the City of London, the Oxbridge hi-tech clusters (Rominj & Albaladejo 2002; Athreye 2001; Keeble et al. 1998, 1999, 2000; Lawson et al. 1998; Segal, Quince, Wicksteed 1986, 2000; Keeble 1989), Silicon Glen and motor-sport engineering, (Henry & Pinch 1998). But the evidence is largely qualitative, based on the subjective perception of researchers (Albaladejo & Rominj 2000; Oakey & Mukhtar 1999). In general, there had been a lack of research into clusters in Britain until 1998 (Hoffman et al. 1998). An exception has been Scotland, where Porter's Competitive

Advantage of Nations methodology was rigorously applied in 1992. The Scottish Executive, SE, Local Enterprise Companies and local authorities in Scotland have since then, (notably since 1997), used cluster models to inform their work on economic development and on specific cluster initiatives.

1.5.1 Cluster Policy: the Case of Scotland

With the steady decline in Scotland's heavy industry since the end of the second world war especially in shipbuilding, steel and mechanical engineering, the traditional industrial heart of Scotland experienced substantial decline over three decades. Following this, the flow of inward investment in Scotland, particularly in the electronics sector, contributed significantly to the restructuring of manufacturing and to new job creation. Scotland had a deep experience of fostering clusters, due to the industrial regeneration that started during the 1970s. The form of Scottish industrial organisation at that time was steered by the Scottish Development Agency (SDA), which targeted electronics as a critical sector for Scottish industrial development. The impact of this cluster in Scotland has been large in terms of employment, capital inflow, and the upgrading of production techniques in the Scottish manufacturing base (McCann 1997).

However, the degree to which Scottish electronics was embedded in the regional economy has been challenged by many, (Turok 1993; Young et al. 1988). The ability of the electronics industry to influence its own development has been limited. FDI's value-added and knowledge generation have remained largely abroad with suppliers, mother plants, or R&D centre, and there has been a lack of leading-edge knowledge integration. This has resulted in a 'weak' cluster with low local product demand, few backward value-adding linkages, and only exogenous knowledge generation. There has been a limited perspective by public agency actors, and a lack of endogenous knowledge networking, (Molina & Kinder 2001). As a result, increasingly policy has shifted towards improving the value of foreign investment in the local economy, for example, by linking foreign investors to local supply chains, by deepening links with local research providers, and by supplier development programs (Brown & Raines 2000).

It is evident that Scotland's industrial policy is largely built around an extensive clustering programme. SE defines a cluster as an economic development process (Brown 2000). There is limited importance attached to geographic boundaries. SE has a light-touch facilitative role, mainly being market and business driven. The relationship between meso-level and micro-level economic promotion ensures an overall goal alignment for both economic agencies and industry (Brown 2000). The measurement and evaluation of clusters has involved experimenting with balanced scorecards (Kaplan & Norton 1992). The evaluation is infrequent, but is used to modify the approach and to shape policy. The reason for Scotland's decision to incorporate clustering concepts into its industry policy was given by Dr. R Crawford (CEO, SE), 'Scotland is a small economy and the commercialisation of R&D is one of its biggest problems, together with the weak level of firm creation. Successful firms don't just happen - some do, but the majority do not. Clustering also helps the players to understand the bigger picture'.

Feser (1998) identified two different types of cluster policies; 'cluster-specific' and 'cluster-informed' strategies. Cluster-specific policy was on the development of identified clusters by mapping the cluster and its characteristics by means of SWOT analysis, whereas cluster-informed policy gave more attention to the improved implementation of individual development initiatives. In Europe, countries such as Denmark, Finland and the Netherlands have a cluster-specific policy, whereas Germany, Austria, Belgium, and Sweden have cluster-informed policy. Scotland uses a hybrid of the two. The starting point in cluster analysis was based on Porter's concepts, (Bergman & Feser 1999; Lagendijk 1999a) with a strong emphasis on community and thus in mapping industries, firms and stakeholders. The action plan is then converted into a cluster-informed strategy, developed 'bottom-up', in consultation with industry actors and stakeholders, to allow local agencies to harness competitive forces and to improve the effectiveness of local interventions. Currently there are eight active, explicit cluster initiatives in which the Scottish Enterprise Network is involved. These were identified as part of a research exercise by Porter's Monitor Group in 1993. Divided into three 'waves' each cluster was selected for its growth potential and long-term sustainability. They were biotechnology, creative industries, forest industries, food and drink, optoelectronics, semiconductors, energy and tourism.

1.5.2. Scottish Policy on High Technology Clusters

High technology activity in Scotland has been mainly driven by a conscious design and the implementation of public policy over many decades. A principal objective of SE is to help companies in Scotland to compete in the global marketplace, and nowhere is this more important than in the hi-tech industries. From a policy perspective, SE has marked out key initiatives like the development of leading technology clusters, which capitalizes on Scotland's research base. SE has specialised "cluster" teams, which have targeted Scotland's leading-edge industries and technologies, including biotechnology, energy, creative industries and microelectronics. SE's approach to the technology-based sectors, in particular, combines a range of different policies to address barriers, like:

- Access to funding for the technology-transfer process,
- Start-up venture finance,
- Entrepreneurial capacity and
- The capability of management in new businesses in the sector.

SE’s approach to these industries has altered radically since the first cluster strategies were launched, responding to a period of intense change for technology sectors worldwide, (Micro & Opto Electronics Cluster Review & Strategy, SE 2005). Following extensive consultation, SE’s approach is now more informed by market opportunities. Important initiatives like the Alba Centre, the Proof of Concept Fund and the formation of three Intermediary Technology Institutes – ITI Techmedia, ITI Life Sciences and ITI Energy, have contributed to that change by providing market-driven and demand-led funding for commercially focused R&D. These are all helping hi-tech firms to put new ideas into action. Scotland’s national economic development framework, entitled ‘Smart, Successful Scotland’, has reflected a qualitative shift in the premises of the nation’s economic growth, from a strategy emphasising the attraction of inward investment (on the basis of low-cost advantages, low value-added and labour-intensive activities), to one which attempts to redress issues of productivity, competitiveness and innovation (SE 2001).

Based on an awareness of this policy shift, the research of this thesis investigates performance, innovation, networks, and the embeddeddness of the firms in the hi-tech cluster. Embeddeddness is evaluated here by investigating matters like the extent of sourcing from local suppliers, the input to the innovation process (in terms of innovative idea from within the cluster), the firm’s recruitment of staff locally, the extent of informal and formal linkages and, finally, spillover benefits. The selection of life sciences, opto-electronics, microelectronics, digital media and software clusters for this research is in light of SE’s cluster approach on technology-initiatives, (SE 1998; Scottish Technology Industry Monitor 2002; Biotech Scotland, Framework for Action 2002).

1.6 Research Methodology

This research involves empirical analysis of performance, innovation, and networks of hi-tech firms. This was based on a multiple sampling procedures in order to create a sample of firms (see Chapter 6, sections 6.2 & 6.3). The procedure on primary source data collection was as follows:

- 836 firms were identified as hi-tech firms covering 5 sectors.
- The distribution of firms sector-wise was as follows: microelectronics 187, life science 150, optoelectronics 80, digital media 189, and software 230 (see Chapter 6).
- The data were collected by multiple data collection techniques, (postal questionnaire, electronic questionnaire, administered telephone interviews), (see chapter 5).
- The questionnaire captured data on performance, collaboration, resources, embeddeddness and innovation, (see chapter 5, section 5.3).
- A database was constructed that involved 158 firms, for each of which 131 variables were measured. That data has been put into SPSS format.

Essentially, this database allowed detailed cross-section analysis of many important topics. The summary statistics and the preliminary analysis was done using SPSS. The applied econometric simultaneous equations model, on hi-tech performance, innovation and networks was performed using Limdep software. Both Shazam and Limdep were used for the econometric work that enabled hypothesis testing to be undertaken on key topics.

1.6.1 Development of the Research and the Overview of Thesis

This thesis is structured into five parts as follows. This part, (Part I) has two chapters and presents an overview of the thesis, the motivation for this research and the problems that are addressed by this study and the research contributions. **Chapter 1** (the current chapter) presents an overview of the thesis, and introduces various theoretical concepts and definitions of the terms that are intrinsic to this research, and to the thesis structure. **Chapter 2** introduces the research rationale and objectives, and identifies the problems that are to be addressed by this thesis.

Part II contains chapters 3 and 4. **Chapter 3** provides an extensive literature review of works relevant to this research on hi-tech firm performance, innovation and networks. The first section focuses on the ‘R&D, Innovation and Productivity’ studies, in particular, the

‘Production-Function framework’ approach (Jaffe 1986; Griliches & Mairesse 1984), and the ‘Knowledge Production Functions’ approach (Pakes & Griliches 1984; Loof & Heshmati 2002). Next, key econometric contributions and research on the CDM model (Crepon et al. 1998), and its variants (van Leeuwen & Klomp 2001; Janz et al. 2004), are reviewed in detail. Then studies on the factors fostering innovation in firms, are reviewed next, by focusing on various internal and external resources which impact upon innovation and performance. The last section reviews the spatial proximity, knowledge spillover and embeddeddness literature. It thus aims to bring together those significant contributions that lay the foundation for this empirical study.

Chapter 4 presents evidence on the emergence of high technology in Scotland, by setting out a detailed description of the different stages in the history of its evolution in Scotland. Initially it examines the roots of high technology in the Scottish Economy, the de-industrialisation followed by the regeneration strategy of 1970’s, and the different phases involved in the process of inward investments by the various MNC branch plants. This is done in the light of policy approaches at different points in times, specifically, the transition over time of the SDA into the SE. The extent of embeddedness in Silicon Glen is reviewed next. The identification of hi-tech clusters in the light of the DTI’s industry policy on knowledge-based economy in the UK is examined next. The SE initiatives on the hi-tech sectors in the wake of ‘Smart Successful Strategy’, and the overview of the current hi-tech structure in Scotland are examined next. This gives the rationale behind the selection of the five hi-tech sectors, for this empirical study of Scottish hi-tech firms.

Part III contains chapters 5 and 6, which build up a picture of the typical hi-tech firm in the sample. Further, it outlines the instrumentation, fieldwork and the sampling methodology used in constructing the sample.

Chapter 5 deals with the instrumentation which was used successfully to collect the empirical evidence, in primary source form. It illustrates the novel features in the formulation of the instrumentation, focussing on unique features in the questionnaire design, and also in its implementation. It details the structuring of the questionnaire into five sub-headings, influenced by dense conceptual and theoretical considerations and empirical evidence. Robust measures that overarch different innovation stages, so as to overcome the drawbacks involved in using a few innovation variables that does not fully capture the innovation process in hi-tech firms, are incorporated. The information collected enables a clear and distinctive picture of Scottish hi-tech firms to be drawn. It outlines the key indicators of innovation, such as R&D expenditure, sales from new products etc., supplemented by the qualitative indicators like objectives, obstacles and strategies on innovation. This rich data on different innovation dimensions allows a more comprehensive verification of the hypotheses being tested, and helps to achieve robust results, and thus meaningful conclusions.

Chapter 6 details the sampling procedure that was used in constructing the sampling frame. It illustrates the different stages involved in the process of extracting the sample frame of 836 firms from the Scottish hi-tech population. A multi-stage sampling technique, involving cluster, quota and stratified sampling is explained. This is followed by a preliminary analysis on this data in the cross-sectional dimension, that lays the ground work for further advanced analysis and econometric modelling in Part IV. Key innovation variables are related to firm characteristics, such as age, size and sector. The firms are further characterised on a spectrum of innovativeness, from highly innovative, to innovative, and non-innovative, to describe the innovation behaviour of firms. Further, it compares the hi-tech sample with the 'Scotland population', which constitutes all sectors in Scotland, with respect to the figures on start-up, size, export, patents, R&D intensity etc. This consolidates evidence on the prominence of high technology in the Scottish economy. Thus the characteristic features of hi-tech firms and performance are presented.

Part IV is the main analytical part of this thesis and has four chapters, chapters 7, 8, 9 and 10. It deals with the analysis of the data gathered, using statistical and econometric analysis, and presents the main results.

Chapter 7 investigates extensively hi-tech performance, and specifically, the performance of the highly dynamic, hi-tech SMEs in relation to larger hi-tech firms. The analysis involves the empirical testing of hypotheses on innovative performance, and on their growth heterogeneity, across firm size. The literature on the theoretical and empirical methods that are relevant to the two key hypotheses is also reviewed. The first one is illustrated by testing the Shumpetarian hypothesis (Schumpeter 1942, 1950) regarding firm size and innovation performances. Primarily, the non-linear relation between size and innovation is estimated using robust techniques. Specifically, it estimates a regression of a cubic function, permitting the identification of inflection points and nonmonotonicity in the relationship. It does so using a number of different innovation indicators that overarch the measurement of all stages. Next, hi-tech firm growth performance is explored by the empirical testing of Gibrat's Law of Proportionate Effect on data for hi-tech firms. This investigates the growth performance of such firms, in relation to their size. The growth rate of turnover, employment and labour productivity, for four different periods, revealed robust results. Thus the specification and estimation methods used produce results which appears to be general, conclusive and robust, thereby illuminating the key hypotheses.

Chapter 8 deals with a detailed investigation of the international orientation of firms. Specifically, it presents an overview of the internationalisation of hi-tech firms. It focuses on the firm's international alliances and its export performance. This evaluation of internationalisation in firms also reveals the importance of their embeddedness in local networks, and their local markets. New insights are provided into the network behaviour of internationally focused firms, in contrast to firms without any international networks. Building on the evidence of hi-tech innovation and growth performance, this chapter explores factors which determine the export performance, and the export decision, in a multivariate analysis, using a Tobit model with sample selection. It significantly contributes to the vast literature on export performance in firms. The multivariate tobit analysis identifies econometrically the contributions of the independent variables to the firm's export decision, and also indicates the explanatory power of these variables for export performance. It also has policy implications, as it can direct the policy to increase the internationalisations in SME's, by devising strategies in the light of these findings. The preliminary analysis performed in this chapter, investigates the:

- Impact of firm size on the export performance of hi-tech firms
- Export performance of innovators versus that of non-innovators

Robust export measures used to evaluate, thus facilitates the understanding of the hi-tech export performance to a great extent.

Chapter 9 presents an in depth analysis of hi-tech firm networks. The topics of knowledge networks and embeddeddness are examined, by presenting the statistics on key alliance intensities with different partners. Further, it empirically tests the following hypotheses:

i) Are SMEs more dependent upon external networks than large firms for innovation? This is done using a tobit model.
ii) Does proximity to a firm's collaborators increase its network intensity?

The embeddeddness aspect is analysed with respect to topics such as geographic pattern of networks, distribution of sales & purchases, informal links and spillovers.

Chapter 10 deals with the estimation of an econometric model developed specifically for this research on innovation, networks and performance of firms, in the hi-tech sectors of Scotland. The data and variables in the model, the formulation of model, its specification and the estimation of the model are all illustrated. The structural model developed explains the firm performance by innovation output, and the innovation output by innovation investment. The model comes under the conceptual framework of the CDM model that brings together three important, but largely separated, lines of empirical research into one encompassing model, viz. the determinants of R&D investment in firms (Freel 2003; Rominj & Albaldejo 2002), the knowledge production functions (Pakes & Griliches 1984), and the Cobb-Douglas production function (Jaffe 1986). The estimation results are discussed in the last section of this chapter. The results provide insight into the dynamic innovation process in hi-tech firm, the effect of firm's external networks and other demand-pull and technology-push factors. It captures the direct impact of these factors on each of the different stages of the innovation process (innovation decision, innovation input and output), and its indirect impact on performance. The results are of great relevance to the current Scottish policy on technology clusters, which emphasise on networks, innovation, and the inter-dependence of firms.

Part V concludes this thesis by presenting a summary of the main findings and by presenting conclusions, policy implications, solutions and recommendations.

1.7 Conclusion

This research offers new and practical insights into empirical matters which underpins our understanding many of the challenges that confront government and organizations in Scotland. This research explores the relationship between networks, innovation and performance by examining the empirical evidence on firms. An empirical test is undertaken of models explaining: the nature of the firm's portfolio of multiple alliances; its determinants; and its effects on innovative and economic outcomes. It will apply econometric methods in a new way to extensive data on hi-tech firms in Scotland, collected by using structured questionnaires. Both qualitative and quantitative variables are used. A combination of different measurement variables, rather than the conventional (simple measure) method is identified to capture innovation at the firm level. The findings should be of significant interest to researchers, practitioners and policy-makers alike.

Chapter 2 Identification of Key Research Problems

2.1 Introduction

This research aims to analyse extensively Scottish hi-tech firms in five knowledge-based sectors of: life science; microelectronics; optoelectronics; digital media; and software clusters. From a microeconomic approach, this research aims to uncover related conceptual and empirical aspects. Thus, it reveals strength and weakness in the performance and innovativeness of hi-tech firms, by analysing new data on them, from primary sources, by fieldwork methods in Scotland.

This thesis examines the extent and content of inter-firm links of the firms within these clusters (Powell 1996; Oerlemans et al. 2001; Tether 2002; Stuart 2000) and also their embeddedness (Keeble et al. 1998; Lawson et al. 1998). It examines how firms effectively utilise their internal (Oerlemans et al. 1998; Lenox & King 2004; Hoopes et al. 2003; Barney 1991; Prahalad & Hamel 1990), and external resources and the ways in which these resources will increase their innovativeness and competitiveness (Rogers 2004; Romijn & Albaladejo 2002; Freel 2000b, 2003; Zander & Kogut 1995; Love & Roper 1999). Additionally, a review of the economic policy is done using secondary data analysis. This involves considering: key SE strategies for promoting hi-tech firms in Scotland (Brown et al. 1999; Tranfield et al. 2003; Raines 2001; SE 1998); the industry policy adopted before by the SDA (Rich 1983); and the evolution of high technology in Scotland in the past (Turok 1997; Botham 1997).

This chapter provides the rationale behind the research objectives. Several factors intrinsic to hi-technology have inspired this research into hi-tech performance, innovation and networks. In the current global setting, it is important to understand the innovation-intensive hi-tech firms that have well-positioned several economies world-wide, competing effectively on innovativeness and strong performance, with potential to increase the number of start-ups, create jobs and to revive stagnant industries, (Audretsch 1998; Becattini 1989; Camagni 1991; Steiner 1998; Best 1990; Piore & Sabel 1984). The following sections present the rationale, objectives and the key issues addressed by this thesis. In doing so it aims to provide a better understanding of policy related, conceptual and empirical aspects. Section 2.2 describes Scottish economic policy initiatives on clusters, and on hi-tech sectors in particular. This consideration has been a major factor motivating this research. Section 2.3 explains the motivation behind the structural econometric model developed, and how it links firm's performance, innovation and networks, within a simultaneous framework. Section 2.4 explains the logic behind investigating, for the hi-tech case, how small firm performance e.g. on innovative and growth, compares to large firm performance. Section 2.5 details the rationale behind developing key measures of economic parameters, innovation and networks of hi-tech firms. As Chapter 1 (section 1.1) has already indicated, different sophisticated innovation indicators may be used to capture the complex innovation process in firms (Hagedoorn & Cloodt 2003).

2.2 Policy Approaches in the UK on Innovation and Networks in Firms

At the national level, the UK currently faces transition to a new phase of economic development, moving from competing on relatively low business costs, to competing on unique, high value added (and innovative) products and services, (Porter & Ketels 2003). Even though there has been significant progress on several dimensions of the UK economy over the past decade, compared with competitors, in terms of strong growth in labour force utilization, and an increase in growth rate of GDP per capita (and in trade and foreign direct investment levels), there still exists a large productivity gap between the UK and its major competitors. The innovation review commissioned by the DTI in 2004 covered three key issues in the field of innovation in firms in UK, (Pittaway et al. 2004; Edwards et al. 2004).

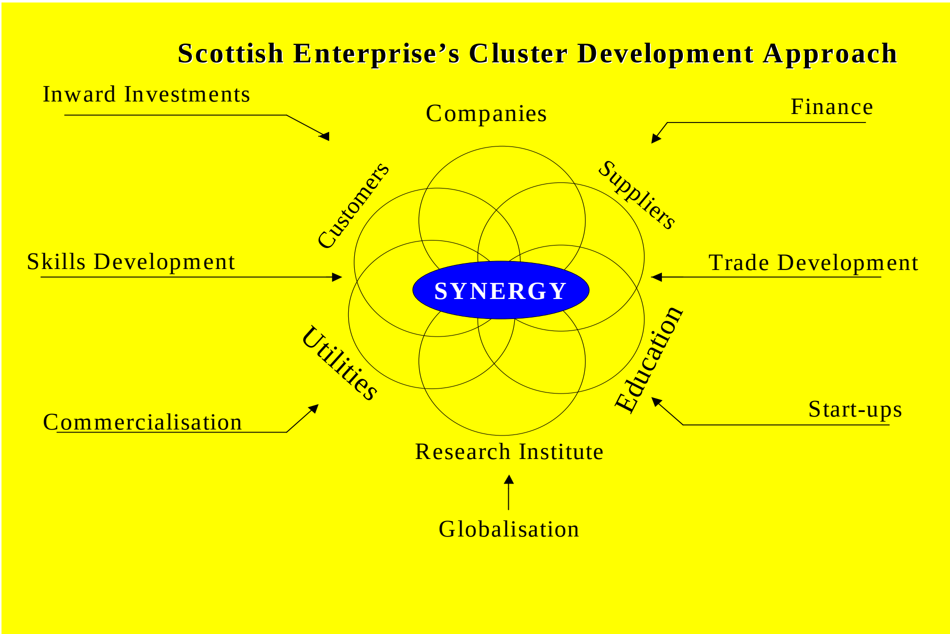
- The extent to which a firm's relationship with external organizations affects its ability to innovate and perform.
- The evidence on the adoption of promising practices in organizations.
- Strategies for value creation like innovating to produce products or services generating more revenue.
- Strategies helping to move to a position in the value or supply chain where the products and services generate more value.

These issues, at national and particularly at regional level (Scotland), have inspired this research and its objectives. Such considerations motivate this research on hi-tech firms.

2.2.1 Scottish Enterprise Approach towards a 'Smart Successful Scotland'

Cluster development has featured as part of the overall strategy of SE (see Figure 2.1). The highlights of SE's cluster development approach are informal and formal community building (Raines 2001). This is achieved by facilitating measures on linkages by supporting networking and internal relationships within the clusters, measures enhancing common source of competitiveness that are external to a firm but internal to the cluster as a whole, (quality of specialised skills, special research facility etc), and lastly by creating an awareness of a cluster's international competitiveness, reinforcing the internal community by a recognition of collective advantages and external rivalry. Working in partnership is vital in the implementation and delivery. It combines the efforts of the Scottish Executive and SE, with the support of the business community, trade unions, educational institutes, and public sector.

Figure 2.1



The Framework for Economic Development in Scotland (FEDS) provided the base for the 'Smart Successful Scotland' strategy in 2000, which is in essence the Scottish Executive's strategic direction to the Enterprise Networks in Scotland (SE 2001). This blueprint details how to create the conditions for business growth and innovation, underpinned by a skilled, productive workforce to meet the objectives of improved productivity and sustainable growth. The focus is based on three broad themes:

- Growing businesses: taking forward entrepreneurial dynamism and research & development to deliver innovative companies growing in scale.
- Global connections: taking forward aspects of physical and electronic infrastructure, together with building the global connections of Scottish businesses to create world-class locations and connecting to the global economy.
- Learning and skills: developing skills to make best use of human capital.

Within the framework of a ‘Smart Successful Scotland’, SE has outlined initiatives focussing on stimulating greater investment in innovation and commercialisation, supporting businesses to launch new products and process improvements, and creating new spinouts from universities and research institutes. In the wake of these SE initiatives, this thesis examines: the performance of five key clusters in Scotland; interdependence of firms; various support organisations in the community; and the policies that enhance innovation and competitiveness of firms. It does so using empirical methods, and will thus contribute to an evaluation of the effectiveness of SE’s strategies. It will provide insights into the present and future SE strategies on leading technology clusters, and will assist in making judgements on the effectiveness and implications of these SE policies. In the light of the results obtained from this analysis, it will be possible to offer support for policy recommendations.

2.2.2 Scottish Enterprise Initiatives for Technology Clusters

SE believes that knowledge-based industries have the potential to enable less developed and low regions to take the ‘high road’ to economic development, thus contributing to higher value-added activities, wages and standard of living. The technology clusters plays significant role in driving forward the knowledge economy, creating wealth and high-quality jobs as a result of its innovation (SE 2000). The Scottish Executive’s Minister for Enterprise and Lifelong Learning has suggested that ‘In Scotland, we cannot compete through low cost or a low skilled workforce. We must promote our most innovative businesses and encourage people to develop their science and technology ideas’. SE has put in place various initiatives targeting hi-tech clusters. The key to their approach is the development of leading technology clusters, which capitalise on Scotland's research base, and target high-growth start-ups. Initiatives such as this are the:

- Biotechnology Business Advisor Service (BBAS); Creative Industries Strategy for digital media, Creative Industries Park in Tayside aimed at games sector; and the Alba Centre aimed at opto-electronics, embedded software and micro-electronics, in order to develop businesses, commercialise research and create spinouts.
- ‘Proof of Concept Fund’ to provide development funding to early-stage ideas within Scottish universities and research institutions. The ‘RSE Enterprise Fellowship Scheme’ giving financial support to university-based entrepreneurs**.**
- Scottish Co-Investment Fund to give support to private sector venture capital funds and incubators (Hillington Park Innovation Centre).

- Small Company Innovation Support, aimed at creating an environment that encourages the introduction of new products/ process and the market launch.
- More recently, three Intermediary Technology Institutes (ITI) in Energy, Life Sciences and Communications Technology & Digital Media, have been set up to support the development of market focussed, pre-competitive technology for high growth businesses, utilising existing research capacity.
- Co-Investment Fund, in partnership with the private sector, to provide risk money for early stage, businesses.
- Business Gateway, launched with public sector partners, to facilitate a single access point for all publicity funded business support services.

In the light of these SE initiatives on technology clusters, this thesis focuses on the five technology-based clusters of: life science; microelectronics; optoelectronics; digital media; and software. It aims to evaluate how well the firms in these clusters have benefited from these initiatives, and to determine the characteristics, and various attributes, of the firms that drive these hi-tech clusters.

2.3 Models and Hypotheses

The emergence of a few relatively recent studies, based on the structural approach to the innovation process in firms, is one of the main inspirations of this research. This thesis addresses the relationship between networks, innovation and performance, by examining the empirical evidence on firms, based on the empirical knowledge production function model (Crépon et al. 1998; Pakes & Griliches 1984). The main objective is to establish empirically a link between the input to the innovation process and the innovation output, and how it increases the performance of hi-tech firms, by solving for selectivity and simultaneity biases, (Lööf & Heshmati 2003; Janz et al. 2004; Klomp & Van Leeuwen 2001). This is achieved by building a structural econometric model that allows for the decomposition of the innovation process and its two-way relation with firm performance.

Even though many have empirically analysed the innovation-performance relation, there has been no consensus on the outcome, mainly due to the multidimensionality of both innovation and performance variables (Coombs & Bierly 2006). A common empirical approach for studying the relationship between research, innovation and productivity is a model of a Cobb Douglas form. Most recently, several studies were based on the Pakes and Griliches (1984), knowledge production function, and the empirical knowledge production function model by Crépon, Duguet and Mairesse (1998). The latter is referred to in the literature as the CDM-model. The empirical knowledge production function framework has been widely applied in empirical studies of regional innovation in the US (Anselin et al. 2000), in Italy (Audretsch & Vivarelli 1994), in Austria (Fischer & Varga 2001b) and in Germany (Fritsch 2001).

The basic econometric problems that the CDM model aims to solve are selectivity and simultaneity biases. It provides an explicit modelling framework, for the use of appropriate estimation methods in the presence of; sample selectivity (due to the firm's choice of whether or not to undertake R&D); potential endogeneity of some of the right hand side variables; and the partially qualitative nature of some of the dependent variables (binary or categorical). The approach takes into account that not all firms are engaged in innovative activities. When only the innovating sample is used in some part of the model, the firms are not randomly drawn from the larger population, and selection bias may arise. Therefore, the CDM approach adds a selection equation to the system. When several links in the process of transforming innovation investment into productivity are considered in a simultaneous framework, one possible problem to emerge is that some explanatory variables often are not exogenously given, and there will be simultaneity bias.

Hall and Mairesse (2004), report that a major contributions of the CDM model is that it has set up a relatively simple framework on which others could build, varying or improving the economic specification, data used, and econometric identification and estimation. The general structure of the CDM approach can be interpreted as a three-step model consisting of four equations linking R&D, innovation output and productivity at the firm level. In the first step, firms decide whether to engage in innovation activities (the selection equation) and decide on the amount of money to invest in innovation. This is specified by a generalized Tobit model. Given that the firm has decided to invest in innovative projects, the second step defines the knowledge production function in which innovation output results from innovation input and other factors (Griliches 1995). In the third step, the enhanced Cobb Douglas production function describes the effects of innovative output on productivity. The empirical CDM approach was adopted by Lööf & Heshmati (2003) and Lööf et al. (2003) and was applied to Swedish and Scandinavian data, respectively. Klomp & van Leeuwen (2001, 2002) have also used a CDM approach for Dutch data. Janz & Peters (2002) apply a similar approach to German data, but focus on the link between innovation input and output.

Indeed, the econometric model in this thesis applies the conceptual ideas of the CDM model framework, but in a fashion which is more developed on multiple levels. Extensive modifications are undertaken with respect to specification of the model, variables in the model, and estimation methods, to suit best this unique body of data and tailor to the modelling of specific problems encountered. It is significantly developed to incorporate new features, and to solve for the various difficulties encountered in analysing the complex innovation process, the embeddddness and networking effects on innovation process and their links to the different measures of firm performance. This research, by using a simultaneous equations method, explains how firms can improve their innovativeness and overall performance. This is done by analysing their networking with other firms in the value-chain and also with other public & research organisations, their embeddeddness, and the various impacts of spillover from different sources.

The main problem in using the original CDM here is that the model assumes data to be of a time-series nature. However, the present study is a cross-sectional one even though some of the key variables do indeed capture data over a five-year period, and thus do have a time series dimension. This model incorporates many new features. The first one is with respect to sample selectivity, the selection equation being defined with respect to firm's innovation investment decision, where a binary variable is equal to one if the firm has positive innovation expenditure and zero otherwise. Thus the sample selection is now more thoroughly modelled, as the new selection variable allows more firms in the model as compared to when using R&D expenditures instead of innovation expenditures (104 as compared to 121 firms). Another important contribution of the model is that the treatment of simultaneity is extended to three equations. This is essentially due to endogeniety of some of the variables. This model takes into account a number of feedbacks at different stages of the innovation process, based on the 'success breeds success' hypothesis of Mansfield (1968). One feedback link is from innovation success to the innovation input decision, (Janz & Peters 2002). Another feedback link is from economic performance to innovation (Janz et al. 2004), with firms encouraged by greater economic performance diverting greater inputs to the innovation process. By examining whether a firm's past innovation success determines current innovativeness, the model aims to explain the innovation persistence in hi-tech firms, (Raymond et al. 2006; Geroski 1997).

Another contribution is that the model has embedded within it the firm's networking with external organisations. Here three variables are used to capture the intensity of networking with research, government and customers respectively, allowing one to examine the direct effect, of networks on innovation input, separately from that on the innovation output, and the indirect effect, on economic performance. The differences in impact of these same network variables on the innovation input and output can illustrate the intentions and necessities that drive the firm to collaborate. One important aspect is that the impact of networks on the innovation input, output and performance is determined by controlling for the impacts of knowledge spillovers from different sources, and the firm's own innovation effort. It allows one to control for the impacts of knowledge spillovers from three different sources: market sources (customer, supplier and competitors); educational and public sources (universities, research & government organisations); and internal sources. The choice of three types of network variables was made to reflect the additional impact of knowledge spillovers from the same sources, i.e., market, educational and public sources. Another significant advance is that the embeddedness of firms and its effect on performance are incorporated, a dummy variable for controlling for local networking, as a proxy for embeddedness.

The model explains the different ways in which the various organisational strategies influence the performance and innovativeness of high technology firms by including three variables: the strategies on product innovation, market share and productivity. These three represent the technology-push, demand-pull and the cost-push objectives of the firm respectively. Unlike the CDM model where only the innovative sample is used in the simultaneous part, the full sample (all 151 observations) is used in both the first and second part of the model here. The estimation is done for the innovative sample as well. The purpose is to facilitate a sensitivity analysis, by comparing the estimation results and thus checking the robustness of the results.

2.4 Small Hi-tech Firm Performance

Empirical research in the UK and elsewhere, on the ability of highly networked small technology based firms, has been a strong motivation for this research (Barber et al. 1989) Rominj & Albaladejo 2002; Oakey & Mukhtar 1999; CBR, Centre for Business Research). Even though several substantial small business surveys have been conducted, significant gaps exist, as noted by a survey about research on R&D, technology and innovation in small business in the UK. Hoffman *et al. (*1998) notes that in many of the empirical studies, the analytical treatment of innovation within the SME context is limited, both theoretically and methodologically, and that these studies do not set out to measure comprehensively, and then to link innovative inputs to innovative outputs.

2.5 Indicators of Innovative Performance and Measurement Issues

The vast majority of empirical studies on the impact of innovation and technological change on crucial economic parameters like productivity, employment and international trade performance (see Griliches 1995 and Krugman 1995 for surveys), have used input–orientated indicators on innovative activity, i.e. R&D activity and more precisely R&D expenditures. A consequence of this is that all R&D performing enterprises are innovative merely by definition, even though not all innovators automatically engaged in R&D. The Frascati Manual (OECD 1994) is one of the first methodological documents setting guidelines for collecting and interpreting R&D data. The increasing importance of innovation and the only recently grasped shortcomings of R&D data for economic modelling and policy recommendations, led to the creation of the Oslo Manual (OECD and Eurostat 1997). In commenting on the existing indicators on science and technology, the manual states: "These data have two main limitations. First, R&D is an input. Although it is obviously related to technical change, it does not measure it" (OECD & Eurostat 1997, pg. 12). Patents, most of all patent counts, have been seen as an option to get over this shortcoming, (Acs et al. 2002; Brouwer & Kleinknecht 1999; Hitt et al. 1991; Acs & Audretsch 1989; Griliches 1984). However, patent–based indicators have been heavily criticised as being a poor indicator of innovative outcome (Griliches 1990). Not all inventions are patented, and not all patented inventions lead to marketable innovations.

It is only recently, that the focus of economic innovation research has slightly changed, and that the output–orientated view on innovative activity has gained importance. Community innovation survey (CIS 2001, 2004) data is increasingly being used as a key source in the study of innovation at the firm level in Europe. Data based on the CIS questionnaire is available for the EU member states, and Norway and Iceland also participate in the CIS initiative. The new indicators in the CIS capture the market introduction of new products and services, and their relative importance for the innovators' sales. Furthermore, it contains information on the innovation process and in particular on collaboration for innovation, and knowledge sources. The CIS is based on previous experience with innovation surveys, including the Yale survey and the SPRU innovation database (Klevorick et al., 1995; Pavitt et al. 1987). Compared to the R&D and patent data, innovation output indicators in the CIS have the advantage of measuring innovation directly (Kleinknecht et al. 2002). In the most recent studies, relying on CIS data and using innovation output additional to R&D, Arundel & Pierre (2003) report that almost all studies find a positive and significant relationship between innovation and different measures of firm performance. The first attempt to model the link between innovation input and output was made by Crepon et al. (1998) when analysing productivity effects of innovation, using CIS data. Their approach was later adopted by Janz et al. (2004), Janz & Peters (2002), Loof & Heshmati (2001, 2002) and Loof et al. (2001) whereas Love & Roper (2001) used a different modelling strategy.

As mentioned the research of this thesis draws on the CDM model in developing the applied econometric model explaining the link between innovation, networks and performance, using a simultaneous equations framework. For the application of the full model, a complete set of innovation variables and performance measures was used in this research. It is important to use multiple measures of technological capabilities in firms, so as to provide better insights into key aspects of their organisation. Due to the lack of general conventions on how to define innovation, and how to measure innovation input and output, empirical analyses for a long time were restricted to the use of R&D as a proxy variable. The R&D expenditures, (Acs & Audretsch 1990; Hitt et al. 1991; Hadjimanolis 2000; Acs et al. 2002; Romijn & Albaladejo 2002) and the number of employees dedicated to R&D, (Scherer 1965; Schmookler 1966; Felder et al. 1996; Hadjimanolis 2000), as used in most of the previous empirical studies, are used here as inputs. Moreover, some measures capture the stock of technological knowledge in firms, and others measures captures the flow of technological knowledge. It is seen that stock innovation variables as indicators of performance supports the resource-based theories and flow of technological knowledge is a significant indicator of performance, supporting the dynamic capabilities and knowledge-based approaches, (Coombs & Bierly 2006).

R&D is an important input to the innovation process, but is only one of them, and it does not capture all aspects pertinent to innovation. It is imperative to use more sophisticated measures, that can capture innovation in firms. R&D related inputs make for a minority of innovation expenditures, varying from 15-50 percent depending on the sector being studied, (Felder et al. 1996). Market near innovation activities are not captured by it, (Brouwer &

Kleinknecht 1997) and especially innovation activities of small and medium sized, as well as service sector firms, are heavily underestimated, (Metcalfe & Miles 2000; Kleinknecht & Reijnen 1991; Kleinknecht 2000). This is because they do not have an R&D department, or a separate R&D budget, which makes it difficult to ascertain the total amount of expenditure on innovative activities.

The research of this thesis focuses on the small and medium size firms (SMEs) as 94% of the firms in the sample are SMEs. The sample frame also deals with development firms (6.4%) and new start-ups (6% of the firms are under two years since inception) that do not have R&D expenditures or may not have expenditures that are earmarked as separate R&D expenditures. Moreover, this sample also involves service firms, especially software and embedded software firms, for whom innovation expenditures (Gottschalk & Janz 2001) are a more relevant innovation input measure, as it includes other expenditures, especially for more market near activities other than R&D expenditures. This applies to using patent as an innovation output indicator, as in service sector industries like software. Patents play a minor role in appropriating returns to innovation, and hence are not necessarily relevant (Kleinknecht 2000; Acs et al. 2002; Romijn & Albaladejo 2002).

The drawback of all indicators based on counting, be it patents or number of new products, is that, thereby, all innovations are valued equally. It focuses on both the technical aspects of innovation and the introduction of new products into the market; but it excludes the possible economic success of innovations as such (Freeman & Soete 1997; Stuart 2000). The Oslo manual (OECD & Eurostat 1997) offers a solution in which the share of sales as a result of product innovations (Crepon et al. 1998), are also used here. Still, there are two problems with this indicator: Firstly, sales are related to a time period and the choice of the time period is somewhat arbitrary; secondly, share of sales with new products may have risen because of a general shortening of product life cycles. In order to overcome these two shortcomings, the value added from innovation (sales from new products/services), over the period of five years, and the lead-time of the new product/services, are also taken into consideration. Freel (2005), in studying SME’s in UK points out that the tendency for academic studies to dichotomise innovators and non-innovators, on the bases of observed outputs is likely to be misleading. Rather, it may be more appropriate to further disaggregate non-innovators, for example into ‘tried and succeeded’ and ‘tried and failed’ (Freel, 2000a). In the current context, the likely consequence is an underestimate of the differences between innovators, and genuinely non-innovative firms (i.e. those not attempting to innovate).

Taking into account all the drawbacks of the traditional measures and considering the nature of the data, the measures used here are found to be both more robust and more effective. A broader understanding of innovative performance, in this manner indicates the achievement of a trajectory, from conception of an idea, up to the introduction of an invention into the market place. Different measures are used to distinguish innovators from non-innovators. Innovators, in terms of new product are the firms that have had new product launched (or in the pipeline) and also those firms that have had new product sales in the last five years. Innovators with respect to patent innovation are the ones which have had at least one patent granted or filed in the last five years. In terms of innovation input, innovators are those firms that have in-house R&D or other innovation expenditures, and are also ones with an in-house R&D department. Thus one can attempt to categorise firms, on a spectrum from low-tech to high-tech. The high-tech firms, in terms of expenditure on innovation, are those that have some R&D expenditures; medium-tech are ones that have innovation expenditures other than R&D expenditures; and low-tech ones are those with no expenditures at all. This broad innovative performance approach therefore overarches the measurement of all stages, from R&D to patenting, and new product introduction (Hagedoorn & Cloodt 2003).

2.6. Conclusion

The main objective of this study is to test empirically how the impact of external resources, networking of firms and their embeddeddness raise the innovativeness of hi-tech firms and in turn their economic performance. This approach is used for analysing the firms in Scottish hi-tech clusters. The high significance of clusters of small and medium hi-tech firms, worldwide, with respect to their increased performance and growth, motivates this study. Specifically, the cluster development approach adapted by SE, and their extensive use of strategies fostering networking and interdependence, among firms in a cluster. The research of this thesis builds upon the recently evolved structural modelling approach, of quantifying and explaining the process of innovation that result in performance of firms. A simultaneous equation method is used to estimate the returns from innovation input and networking to the innovation output; the impact of innovation output on the overall performance; and also the feedback link from performance to various stages of innovation. A variety of unique quantitative and qualitative measures are used to capture the complex process of innovation (product/process innovations and radical/continuous incremental innovation) in firms, (both manufacturing and service).

Chapter 3 Literature Review

3.1 Introduction

This chapter provides an extensive literature review of works relevant to this research on high technology firm performance, innovation and networks. It aims to bring together those significant contributions that lay the foundation for this empirical study. The central aim of this thesis is to unravel the complexity in the structure of the dynamic innovation process, by identifying its determinants and how it impacts on the overall performance. This is done by investigating, the links between innovation input and innovation output, through to productivity, by adopting a simultaneous equations approach.

The econometric model for this research builds upon the conceptual framework of the CDM model, (Crépon et al 1998) that brings together three important, but largely separate lines of empirical research into one encompassing model, (Hall & Mairesse 2004). They are: ‘Determinants of R&D investment in firms’, ‘Knowledge production functions’, and ‘Cobb-Douglas production function estimation’. Further, it explains how matters like innovation strategies, internal & external resources intrinsic to competitiveness, and information sources for innovation affect the performance of hi-tech firms. Section 3.2 focuses specifically on the ‘R&D, Innovation and Productivity’ studies. In particular, the ‘Production-Function framework’ (Jaffe 1986; Griliches & Mairesse 1984; Griliches 1995; Wakelin 2000) in section 3.2.1 and the ‘Knowledge Production Functions’ (Pakes & Griliches 1984; Loof & Heshmati 2002; Klomp & Van Leeuwen 2001) in section 3.2.2. The econometric contributions are reviewed in section 3.2.3 and the CDM model and its variants (van Leeuwen & Klomp 2001; Janz et al. 2004) are reviewed in section 3.2.4.

Based on a survey of firms in five Scottish hi-tech sectors, detailed evidence was collected on: firm characteristics, factors influencing innovation capability, cluster-specific details, their innovative performance, dynamic networking and embeddeddness. These are used to assess firm’s innovation, networks and performance. The framework for this empirical work was established by drawing on the extensive theoretical literature and empirical work, on topics like: ‘Determinants of Innovation in Firms’ (Freel 2003; Rominj & Albaldejo 2002; Oerlemans et al. 1998), ‘Knowledge Spillover’ (Caniels & Rominj 2003; Hatch & Dyer 2004; Cassiman & Veugelers 2002; Oerlemans et al 2001), and ‘Knowledge

Networks, Proximity & Embeddedness' (Camagni 1995; Markusen 1996; Lawson 1997). Further, the work builds on different approaches in order to identify the key indicators of innovation activity. These include ‘Absorptive Capacity’ (Freel 2005; Lenox & King 2004; George et al. 2001; Zahra & George 2002; Cohen & Levinthal 1990), ‘Resource-Based-View of the Firm’ (Peteraf 1993; Barney 1991; Hoopes et al 2003; Collis 1991; Prahalad & Hamel 1990; Zander & Kogut 1995; Cohendet et al. 1999; Hadjimanolis 2000; Dosi 1988), ‘Inter-Firm Alliances’ (Lechner 2001; Yli-Renko & Sapienza 2001; Stuart 2000; Dodgson 1996), and ‘Alliance & Innovation’ (Nesta & Mangematin 2004; Porter & Ketels 2003; Oerlemans 2001; Baum et al 2000; Love & Roper 1999; von Hippel 1998), and ‘Hi-tech Agglomerations/Innovative Milieu’ (Keeble et al. 1998; Camagni 1991; Aydalot & Keeble 1988). Section 3.3 deals with factors fostering innovation, 3.3.1 focus on internal resources and 3.3.2 on external resources impacting the innovation and performance. Section 3.4 focuses on spatial proximity, knowledge spillover and embeddeddness.

3.2 R&D, Innovation and Productivity

The contribution of R&D to the firm’s productivity is well documented. Mairesse & Sasseno (1991), surveyed 18 econometric studies at firm-level in the US, Japan and France between 1969 and 1988 and concluded that the research on the impact of R&D on productivity differs in the results, estimation methods, and model specifications. The most common empirical way of evaluating the effects of R&D on firm performance (productivity) is based on the theoretical production-function framework. Here, the theoretical concepts of the relation between R&D, innovation and productivity are discussed and the empirical work based on these concepts is examined. In particular, the approaches emphasised are the:

- Production-function approach (Griliches 1995; Wakelin 2000; Mairessee & Mohnen 2004)
- Knowledge production function (Pakes & Griliches 1984; Oerlemans et al. 2001b; Fischer & Varga 2002)
- CDM model and its variants (Crepon et al 1998; Loof & Heshmati 2002).

3.2.1 Cobb-Douglas Production Function Approach

Pioneer work that is based on the production-function framework was undertaken by Solow (1957) who used a Cobb-Douglas production function for evaluating the role of innovation for economic growth. His finding is that the traditional inputs of the production function, i.e. labour and physical capital, only explain a fraction of economic growth. The remaining fraction (Solow's residual) results from technological progress. The econometric studies that followed this lead, estimated the R&D elasticity or rate-of-return of R&D within the analytical framework of a Cobb-Douglas production function, where, in addition to labour and physical capital, R&D capital is the third input factor, (Minasian 1969; Griliches & Mairesse 1984; Mairesse & Mohnen 2001). The Cobb-Douglas specification can be written as

$$Q_{it} = A\, e^{\lambda t}\, C^{\alpha}_{it}\, L^{\beta}_{it}\, K^{\gamma}_{it}\, e^{\,\varepsilon it} \qquad 3.1$$

where, Q is a measure of output (actual production or sales, or value-added), C is the physical capital stock, L is the labour input, and K is the research capital. A denotes a constant; α, β and γ are the elasticities of production with regard to physical capital, labour and R&D; λ is the rate of disembodied technical change; ε is the error term for the equation reflecting the effects of unknown factors, approximations and other disturbances; and the indices i and t denote the firm (or the sector) and the period (usually the year) respectively. Within this framework the studies focus mainly on the estimated elasticity γ of R&D capital, as well as its marginal productivity or 'rate-of-return' $\rho = \partial Q/\partial K = \gamma(Q/K)$. Research focussing on the R&D elasticity includes both cross-section and time-series estimates, (Griliches 1986, 1995; Jaffe 1986; Hall & Mairesse 1995; Kwon & Inui 2003) Research focussing on R&D rate-of-return include Wakelin (2000); Griliches & Mairesse (1983); Harhoff (1988); Link (1981); and Mansfield (1980).

Survey of the literature (Mairessee & Mohnen 2003) show that the estimated output R&D elasticities range on an average from 5% to 30% and the R&D rate of returns vary between 10% to 80%, and are significantly higher for the scientific sectors than for other manufacturing industries, Griliches & Mairesse (1984) obtained an R&D elasticity of 18% for firms from scientific sectors in their sample, and an elasticity equal to virtually zero for firms in the other industries, (the average estimate for all firms amounting to 5% (Mairesse & Sassenou 1991) The two different ranges of variations are due to the different types of estimation methods and data. The cross-sectional estimates are usually higher compared to time-series estimates. In most of these studies, R&D expenditure is found to have a positive and strong influence on productivity or economic performance, (turnover or value added), (Hall & Mairesse 1995; Griliches 1986; Mairesse & Mohnen 2001; Arundel et al 2003). However, the advantages of R&D are shown to decline when its effects are evaluated over time, (Klette & Kortum 2002). However, it is seen that R&D expenditures account for only a modest part of the total innovation input by the firm, (Brouwer & Kleinknecht 1997). Recent studies have substituted the R&D variable by the innovation investment variable, (Lopes & Dodinho 2005; Klomp & Leeuwen 2001; Gottschalk & Janz 2001; Loof et al 2001), which involves R&D expenditures, industrial designs, and training, licensing and innovation-related fixed asset investments.

3.2.2 Knowledge Production Function Approach

It is evident that the focus of empirical innovation research has, in recent times, shifted from innovation input to innovation output. Crepon et al (1998) stressed that it is not R&D input, but rather innovation output that influences firm's productivity. Parallel to the empirical research, based on Cobb-Douglas production function, another strand of studies has tried to estimate the link between R&D inputs and innovation outputs at the firm level, in terms of a knowledge or innovation production function, that explains the transformation of innovation input into innovation output, (Griliches 1998). It relates R&D to patents, (Griliches 1990) or R&D to innovations, (Klinknecht & Mohnen 2002). The Cobb-Douglas production function, as seen in Eq. 3.1, does not measure this relationship. The neglected link is what Pakes & Griliches (1984) label as 'the knowledge production function', i.e. production of commercially valuable knowledge or innovation output, (Loof & Heshmati 2002), and is represented as a set of three equations.

$$k = \beta^1_o + \sum_m \beta^1_m x^1_m + \varepsilon^1 \qquad 3.2$$

$$t = \beta^2_o + \beta_k k + \sum_l \beta^2_l x^2_l + \varepsilon^2 \qquad 3.3$$

$$q = \beta^3_o + \beta_t t + \sum_j \beta^3_j x^3_j + \varepsilon^3 \qquad 3.4$$

Equation (3.2) is an innovation input equation, where k is R&D expenditure. Equation (3.3) is innovation output, where t is either patents or other measures of knowledge capital. Equation (3.4) is the productivity or, more generally, the performance equation The x^1, x^2 and x^3 are variables indexed by m, l, j with corresponding estimable βs) explaining the innovation input, innovation output and performance of firms. The ε^i (i = 1,2,3) are disturbance terms. These are assumed uncorrelated. The innovation output depends on the presence and volume of innovation resources, and the utilisation of the internal and external resources, in the innovation process (Oerlemans et al 2001b; Freel 2005). A considerable body of research has been developed, examining the link between innovation input and innovation output, (Acs et al. 1994; Feldman 1994b; Love & Roper 1999, 2001; Oerlermans et al 2001; Freel 2003; Mairesse & Mohnen 2004).

Within the framework of the knowledge production function, some have added a regional or spatial aspect to it, e.g. innovation networks and/or knowledge spill-over, (Oerlermans et al 2001; Fischer & Varga 2002; Acs et al. 1994; Oerlerman & Meeus 2002; Belderbos et al 2004), and have found that network and proximity are important factors to be considered in the knowledge production function (Audretsch & Feldman 1996). A firm's regional operating environment can influence its innovation outputs, through its effect on firms' investments in technology transfer, networks and R&D, and through its effect on the efficiency with which these investments are translated into innovation outputs (Love & Roper 1999). But Brouwer & Kleinknecht (1996) and Negassi (2004), finds that R&D networks has a weak impact on innovation output.

3.2.3 Econometric models of R&D, Innovation and Productivity

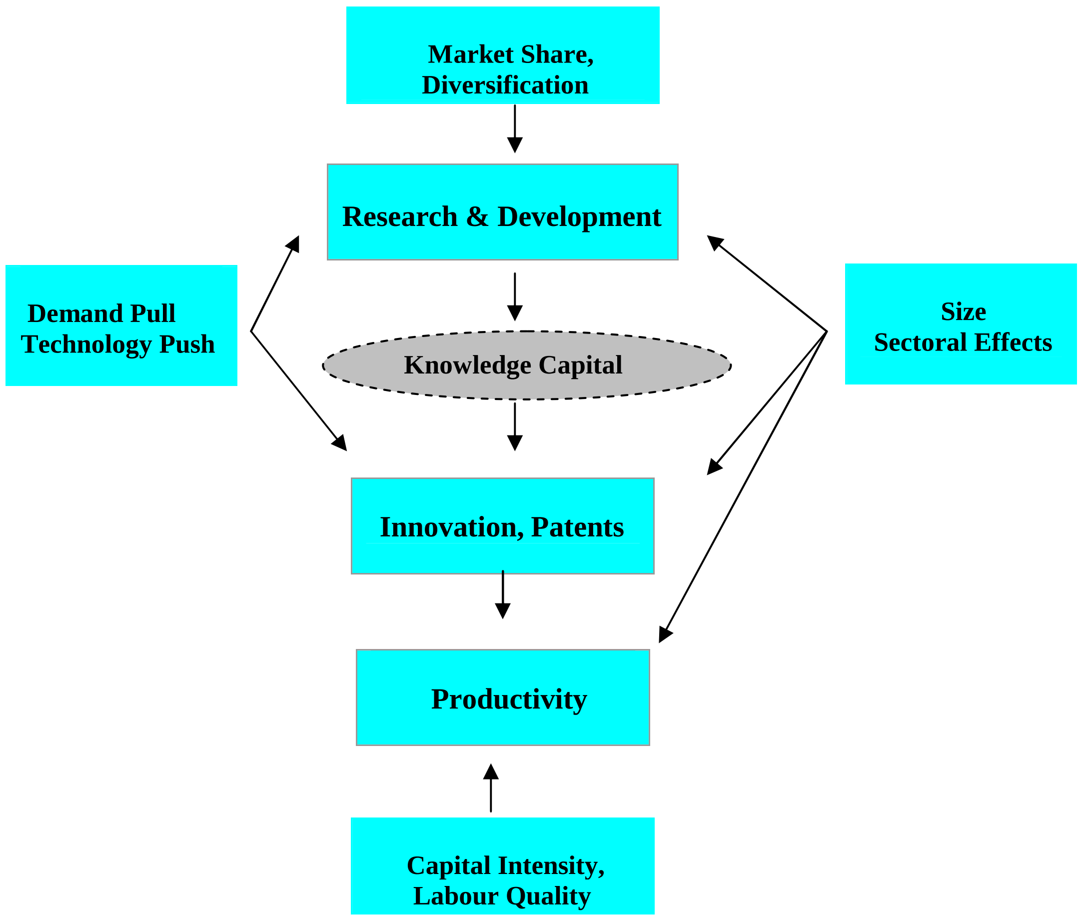
In the last ten years, firm level innovation studies have used new and improved qualitative & quantitative indicators to understand and to measure the innovation process, beyond traditional measures like R&D and patent counts. These studies, based on the new micro-based data provided by the innovation surveys in the European Community, and in other countries, such as Canada in the 1990s, have provided valuable information on several dimensions of the innovation process at the firm level. These dimensions had been previously outlined in the chain-linked model proposed by Kline & Rosenberg (1986), as well as in the National System of Innovation (NSI) literature, (Edquist 1997). The Community Innovation Survey (CIS, 2001,2004) that started in 1993 by the OECD and Eurostat, have initiated a large number of studies in the areas, of the determinants of innovation at firm level, and innovation impact on the economic performance, using advanced applied econometric techniques. It distinguishes between the input stage, the throughput stage, and the output stage of the innovation process (Klomp 2001). The inputs are R&D & innovation expenditures, R&D personnel and national subsidies. The innovation outputs are productivity, new products or processes and share of sales from new products. Finally, the throughput variables are cooperation and sources of innovation information, (Kemp et al. 2003). The empirical studies assessing the impact of innovation on performance differ by focussing on the link between one stage (or stages) in the structure of the innovation process, and performance. They differ in terms of choice of both dependent variables (e.g. sales growth, profit margins, productivity) and explanatory variables (e.g. R&D, patents, innovation output). Most of them find a positive impact of innovation measures on performance (Crépon et al 1998; Lööf & Heshmati 2002).

Many firm-level studies based on the CIS, have applied the knowledge production function to investigate the relationships between inputs and outputs in the innovation process and the productivity effects of innovation in European manufacturing (Janz et al. 2004; Kemp et al. 2003; Ebersberger & Loof 2004). Studies based on innovation surveys for other countries include Parisi et al. (2002) for Italy; Jefferson et al. (2002) for China; Chudnovsky et al. for Argentina (2006); Benavente (2006) for Chile; and Stoevsky (2005) for Bulgaria. Unlike the past empirical work, here the knowledge production function is estimated, not as a single equation, but as a system of equations, as the process from new ideas to innovation output or productivity growth is complex. However, when several links of the process of transforming the input to innovation to productivity are considered, in a simultaneous equations framework, one possible problem is that some explanatory variables very often not be safely assumed to be exogenously given, leading to possible ‘simultaneity bias’ (Green 2003, pg. 379). Most innovation studies are also affected by ‘sample selectivity biases; (Heckman 1979; Green 2003, pg. 781), as only a minority of firms are engaged in formal R&D, or in the case of patents only a few firms have patents. When only the innovation sample is used, the firms are not randomly drawn from the larger population, and sample selection bias may arise. Hence it is inappropriate to limit the focus only on innovative firms. The most significant work in this regard is the CDM model, (Crepon et al 1998) that deals with both simultaneity and selectivity biases.

3.2.4 The CDM Model

The CDM model is a four equations model that includes three relationships, a research equation, that relates research to its determinants, an innovation equation that links innovation output to research input and a productivity equation that links productivity to innovation output. The model flowchart is presented in Figure 3.2. It thus brings together three important, but largely separated, lines of empirical research into one encompassing model (see section 3.1) (Hall & Mairesse 2004). It makes use of the new and improved qualitative & quantitative measures provided by the CIS. Its elements are the determinants of R&D investment in firms, the knowledge production functions, and the Cobb-Douglas production function estimation using R&D, innovation or patents as inputs.

Figure 3.2 The CDM Model



The three equations can be approximated by equations (3.2) to (3.4) in the Pakes and Griliches model. Additionally, there is another equation accounting for the research investment decision by the firm, where the dependent variable is a latent innovation decision variable. Unlike in the Pakes and Griliches model the CDM assumes that the disturbances in the four equations are correlated. The econometric model is specified as a recursive system (Green 2003) of equations, which are estimated using cross-sectional data. There are two versions depending on the innovation output, (patent count, or share of sales from innovation). The CDM model is represented by the following equations:

$$g_i^* = x_{0i}b_0 + u_{0i} \qquad 3.5$$

$$k_i^* = x_{1i}b_1 + u_{1i} \qquad 3.6$$

$$\ln\eta_i^* = \ln E(\eta_i / k_i^*, x_2, u_2) = \alpha_k k_i^* + x_{2i}b_2 + u_{2i} \qquad 3.7a$$

$$q_i = \alpha_I \ln_i^* + x_{3i}b_3 + u_{3i} \qquad 3.8a$$

and

$$t_i^* = \alpha_k k_i^* + x_{2i}b_2 + u_{2i} \quad 3.7b$$

$$q_i = \alpha_I t_i^* + x_{3i}b_3 + u_{3i} \quad 3.8b$$

The first two equations are same in the two versions. g_i^* is a latent innovation decision variable, whose observable counterpart is g = 1 when g* > 0 ; that is, unity if the firm is engaged in innovation, or else zero. k_i^* represents the latent innovation input, (research capital per employee in logs), t_i^* and η_i^* are innovation output, (latent share of innovative sales and expected patents per employee, both are in logs) and q_i is productivity, (measured by the log of value-added per employee). In both versions, the model allows for correlations among the disturbances u_{0i}, u_{1i}, u_{2i} and u_{3i}. The innovation input k in equation (3.6) is an explanatory variable in the innovation output equation (3.7); and innovation output, t, is an explanatory variable in the productivity equation (3.8). Because of the endogeneity of these variables, the explanatory variables and the disturbances can be correlated. As a result, an Ordinary Least Square regression as applied to the Pakes and Griliches model, will led to estimates which are biased and inconsistent.

In CDM model the simultaneity is solved, by using a two-stage estimation procedure. First they apply the method of moments (M-estimation) to the reduced form coefficients for each of the four equations separately. Then they rely on the method of the asymptotic least squares (minimum distance estimator) to retrieve consistent estimates of the structural parameters. For the research equations, a generalized tobit model is used, which has two equations. One is used for accounting for the fact that the firm is engaged in research, and the other is for the intensity of these activities. The x_{0i} and x_{1i} are vectors of explanatory variables; the b_0 and b_1 are associated coefficient vectors; and the u_{0i} and u_{1i} are the error terms. The explanatory variables are the same for Eq. 3.5 and Eq. 3.6, (the propensity to invest in research and the research intensity), (i.e., $x_0 = x_{1i}$). They are size (employment), sector, market share, diversification and demand conditions, and technological opportunities (see Figure 3.2). The last two are dummy variables, as rated by the firms for demand pull and technology push factors. The innovation output is measured as a patent count and also as a share of innovation sales. The patent equation (3.7a), is specified for the use of a heterogeneous count data, with its expectation η_i^* conditional on research and other variables, where k_i^* is the latent research capital intensity, α_k is the elasticity of the expected patent counts with respect to research capital, x_{2i} is a vector of other exogenous explanatory variables, b_2 is its vector of coefficient and u_{2i} is the error term. The innovation sales are measured in intervals, leading to an ordered categorical variable, hence an ordered probit is used to estimate (Eq. 3.7b). The other explanatory variables are the same for both the innovation equations, size and demand pull and technology push dummy variables. The productivity equation (Eq. 3.3a & Eq. 3.8b) is a Cobb-Douglas production function with physical capital, employment, skill composition and innovation output, (latent share of innovative sales or expected patents per employee, both are in logs).

One of the important findings of the CDM model is that simultaneity problem tends to interact with selectivity problem and that both sources of biases must be addressed in applied work. The main results are consistent with many of the stylized facts in the literature. Some of these are that the probability of engaging in research of a firm increases with its size, its market share and diversification, and the demand pull and technology push indicators. The research effort (R&D capital intensity) of a firm engaged in research increases with the same variables, except for size. The innovation output, in terms of patent count, as well as innovative sales, rises with its research effort and with the demand pull and technology push indicators, either directly or indirectly through their effects on research, and the firm productivity increases with the innovation output.

3.2.5 Econometric work based on the CDM Model

The empirical works based on the CDM model and its variants are limited and still evolving. They mainly focus on the manufacturing sector, Jefferson et al. (2002) for China; Benavente (2006) for Chile; Stoevsky (2005) for Bulgaria; Klomp (2001) for Dutch; Janz & Peters (2002) for Germany, Janz et al. (2004) for Germany & Sweden; Mairesse et al. (2006) for France; Loof et al. (2001) comparing four Nordic countries; and Mohnen, Mairesse & Dagenasi (2002) comparing seven European countries. There are very few studies that also look at service firms. Loof & Heshmati (2002), and Loof (2004) compares knowledge intensive manufacturing and service firms in Sweden; Ebersberger & Loof (2005) compare four Nordic countries; and Lopes & Dodinho (2005) examined ten service sectors in Portugal. Several studies that are built upon the CDM model have extended the methodology and methods in several ways, (Klomp & van Leeuwen 1999; Loof & Heshmati 2006 and 2002; van Leeuwen & Klomp 2001; Janz et al. 2004). They do so by using a number of alternative model specifications, different estimation techniques and different innovation and performance measures. To correct for possible sample selectivity bias, and to be able to include both innovative and non-innovative firms at the first stage, most researchers use either a 2-step sample selection procedure, or a one-step generalized

Tobit model. In order to account for possible simultaneity biases, the second and the third stages are usually estimated jointly, either as a simultaneous or as a recursive system. Consecutive studies use the instrumental variables approach, and estimate simultaneously either the whole system or its two-equation second part. Addressing both sources of biases together, the system either includes the Inverse Mill's Ratio from the first two equations or, alternatively, a recursive reduced form method of estimation is used.

The usual implementation of the CDM model involves measuring the final output of innovation as value added per worker, deflated by a broad economy level or industry level deflator. In essence, this is assuming that innovation is cost-reducing rather than demand-shifting, (Lööf & Heshmati 2001). van Leeuwen & Klomp (2001) depart from this specification to estimate a model that explicitly incorporates the demand-shifting effects of innovative output by using revenue (sales) per worker as the productivity measure, to the data of 3000 Dutch firms drawn from the second CIS, and estimates it using methods that control for selectivity in the sample. They include simultaneous links between the input, throughput and output stage of the innovation process, as well as links between the innovation activities and the economic performance as represented by total sales growth or employment growth. Thus, their framework enables only indirect inference on the contribution of innovation to productivity growth. On the other hand, they use more extensively variables that are related to the characteristics of the innovation process itself. The econometric technique they utilize for the estimation is the Full Information Maximum Likelihood (FIML). They find that using revenue per worker as the productivity measure yields better results than value added per worker; and that the return to innovation investment is sensitive to both the technological environment in which the firm operates, and to the estimation method used.

In the work of Loof & Heshmati (2006, 2002), the system relations are specified slightly differently to the Swedish data on both manufacturing and service firms. They use a simultaneous framework only for the links between innovation output and business performance, positing a productivity growth feedback only to the results of the innovation production. For this estimation they employ the three-stage least squares (3SLS) method. They make explicit assumptions concerning the disturbances of the overall model by splitting it into two separate parts. They allow for a limited correlation between the error terms of the equations in the model. They link the two parts by including the Inverse Mill's Ratio from the innovation investment equation (from the first part) in the innovation output equation (in the second part). By doing this, they achieve a more tractable estimation procedure and a direct estimation of the contribution of innovation to productivity growth. They also explored the sensitivity of their results to a number of different changes in specification and variables. In particular, they use a number of variables to measure the innovation success: value added per employee, sales per employee, profit before and after depreciation, and growth rates, and the sales margin, in levels. An important difference is that innovation input is measured by innovation expenditure instead of R&D expenditure.

The results of their analysis show that sample selection bias is less important for these Swedish data than it was for the CDM study, but that simultaneity between innovation output and input produces a downward bias on the innovation coefficient in the productivity (sales or value added) equation. They find that the likelihood of innovating rises with firm size and capital intensity in both manufacturing and services, but that after controlling for industry and obstacles to innovation investment, innovation intensity falls significantly with firm size. The productivity of such investment in terms of innovative sales also suggests diminishing returns, with an elasticity of about one half. An interesting result is that for service firms, the productivity of innovation investments is positively related to the interaction with science. Both in manufacturing and in services, the elasticity of productivity with respect to the share of innovation sales is very similar to that obtained by CDM estimation, (around 0.1). That is, when the share of innovative sales goes up ten per cent, value added increases one per cent, other things equal, while sales and profits show larger increases of about two per cent.

Janz et al. (2004), applying the modified CDM model on knowledge intensive manufacturing firms in Germany and Sweden, find to a very large extent a common cross-country story and some interesting country-specific effects as well. In contrast to the CDM model, they estimate the elasticity of productivity with respect to innovation only for innovative firms in the last part of the model. They allow for potential feedback effects of productivity on innovation output. Therefore, their last two equations are estimated in a simultaneous equation system relying on the instrumental variable approach (2SLS). Moreover, by splitting the model into two parts, they do not allow for full correlation between the four residuals. A two step estimation procedure is applied where in the first step the generalized Tobit model, comprising the selection equation (1) and the innovation input equation (2), is consistently estimated by full maximum likelihood techniques, using observations on both innovative and non-innovative firms. The estimates of this first step are used to construct an estimate for the Inverse Mills' Ratio that is an explanatory variable in the estimation of both structural equations 3 and 4 to correct for potential sample selection bias. In the second step, these two equations are estimated in a simultaneous equation system only for innovative firms using the instrumental variable approach (2SLS).

The model was estimated both for the pooled data set and separately for the individual countries. The probability of being innovative is found to increase with firm size, and market orientation for both countries, but the innovation input decreases with firm size. The science and technology push variables had no significant effect on innovation intensity. Thus, the hypothesis that there might be a cost-push effect of the technological opportunities on innovation intensity, due to the absorptive capacity argument (Cohen & Levinthal 1989, Klomp & Van Leeuwen 2001), did not hold. The demand-pull enhanced the innovation efforts, for Swedish firms. The innovation output was mainly determined by the innovation intensity for both countries. There was a significant feedback effect of productivity on innovation output. Whereas innovation input depended to a large extent on firm size, no direct firm size effect was there for innovation output for the Swedish firms. For German firms there was a significant, negative size effect, indicating smaller firms realized a higher innovation output per employee. The demand pull, or science and technology push variables had no significant effects. Customers as an important information source for innovations or even for cooperation had no significantly higher innovation success. This is at variance with the findings of Crépon et al. (1998) for French or Klomp & van Leeuwen (2001) for Dutch firms, although their demand pull and technology push variables were defined differently. However, the results were in line with the findings of Janz & Peters (2002) for German manufacturing sector. Thus, it seemed that it is not a specific cooperative partner, or information source, that is decisive for innovation success, but rather the networks of cooperation or sources of information. Therefore, nested dummy variables were used to capture potential network effects, however, there was no clear pattern of network impacts.

The productivity effects of innovation on a firms' performance, was found to increase with the innovation output. The export share was significantly and positively correlated with labor productivity. The results highlight the selectivity issue, the Inverse Mills' Ratio, included to correct for potential sample selection bias, was significant in the productivity equation and in the innovation output equation. It was found to be significant only for Germany. The estimates for productivity effects of innovation output are 0.34 in the pooled and 0.27 and 0.29 in the single equations. This is at the upper bound of estimates compared to Griliches (1998) (elasticity of productivity with respect to R&D expenditure around 0.1), Lööf & Heshmati (2003), and Lööf et al. (2003) (elasticity of productivity with respect to innovation expenditure between 0.10 and 0.25 in the level dimension, but slightly lower, around 0.05 in the growth rate dimension). To a very large extent, their results have shown that there is a common story of the innovation productivity link with knowledge intensive manufacturing firms for both countries.

Kemp et al. 2003 applied a modified version of the CDM model on 3042 Dutch SMEs where analysis was carried out in threefold fashion. First, models were estimated for all firms in the data set. Then the same model specifications were used to determine coefficients for the samples of small firms (less than 10 employees) and medium firms (10 and 99) separately. They concluded that the innovation process of small firms differs from medium-sized firms; hence it is important to treat both groups differently. The determinants of innovation intensity are, measured as the total amount of time all employees spend on innovative activities, as a percentage of total available time. Ordinary least squares were used for estimation instead of the Tobit method. However, for the second equation, the innovation output equation, measured as a share of new products or services in total sales, they used a type-2 Tobit model (Amemiya 1985), as a number of firms had zero innovative output. The Heckman two-step procedure (Heckman 1979) was used to estimate it, where in the first step the probit model was estimated by ML and in the second step, the linear regression model was estimated (using OLS) for the firms with a positive share of innovative sales. In the OLS part, the inverse Mills ratio is added to correct for the bias in the estimates. This produced less efficient estimates than ML, but in general estimation results do not differ substantially. The relationship between innovation and firm performance was tested for four performance measures: the turnover growth, employment growth, profit and productivity and found that innovation contributed to turnover and employee growth, but had no effect on the profitability and productivity of the firm.

The main findings were that the innovative input is explained for small and medium-sized firms by different factors. Small and medium-sized firms had more innovative input if they innovated continuously. For small firms performing market research, having contacts with an intermediate organization and cooperation with other firms and research institutes had a positive effect on the innovative input. The national innovation policy had a positive effect on the level of innovative inputs of small firms. The use of national subsidies and contact with the intermediate organization had a significant, positive effect on the innovative input. Furthermore, they found a negative relation between firm size and the innovative input. Export growth had a positive effect on the innovative input. If the sample is split up in small and medium-sized firms, these relationships are only significant for small firms. This finding is in line with previous empirical research (Vossen & Nooteboom 1996, Kleinknecht 2000, Lööf et al. 2001). The negative relationship was especially relevant for small firms. The negative relationship disappeared if the firms were bigger and more homogeneous. A similar argument was given for the positive relationship between export growth and innovative input. With respect to innovation output, the decision to have innovative output was positively influenced by the continuity of the innovation efforts, changes in the organization, the measurement of customer satisfaction and the focus on product innovations. However, contacts with the intermediate organization had a negative effect on the decision to have innovative output. This effect disappears for medium-sized firms. This indicated that contacts with the intermediate organization had a negative effect on the transformation process from innovative input to innovative output. Turnover had a negative effect and turnover growth a positive effect on the innovative output. Innovation contributed to the turnover and employee growth. For small firms, the innovative output does not influence the level of the employee growth. The innovative output had no effect on the profitability and productivity.

Benavente (2006) used data from Chile and obtained results that were somewhat different from CDM while using a model that is almost identical to the original. This variant had, first, a research equation (R&D per worker), a second one that explains innovation (proxied by innovative sales) using R&D intensity, and a third one that translates innovation into productivity differences (measured as valued added per worker). As in CDM, the method of estimation is asymptotic least squares (where the first and second moments of the data are treated as sufficient statistics for the underlying probability distribution), a consistent but not efficient estimator. Benavente (2006) finds that larger firms, and firms with higher market shares in their industry, have higher R&D intensities and that larger firms have a higher percentage of innovative sales. These findings are familiar from other countries, and confirm the Schumpeterian view of innovation as an activity undertaken by larger monopolistic firms (Schumpeter 1950; Galbraith 1952). But contrary to the findings in several of the other papers, he also finds that R&D did not contribute to innovative sales nor do innovative sales contribute to productivity for these Chilean firms (once size, capital per worker, industry and demand pull/technology push is controlled for).

Jefferson et al. (2002) applied the CDM model to 20,000 large and medium-sized Chinese firms and added an equation for profitability, as well as for productivity to the model. He uses size, industry, and the nature of ownership (private, foreign, or government) as control variables for all equations. Industry concentration (rather than the market share of the particular firm), lagged firm profitability, and lagged R&D intensity were all used as instruments for R&D intensity in the new product sales equation. The findings are that size or industry concentration does not affect R&D intensity, after controlling for industry. This may be because they have included lagged R&D intensity in their equation, which will tend to reduce the explanatory power of any other variables due to the widely observed persistence of R&D (Hall et al. 1986). The R&D intensity does influence new product sales, although it exhibits decreasing returns that are related to foreign ownership of the firms. In addition innovative sales are associated with greater productivity and profitability, especially in larger state-owned firms and local government collectives, suggesting that innovation can make a big difference in this sector, even though it is viewed as having an increasingly declining share of output. Jefferson et al computed the total returns to R&D, finding that they are 3 to 4 times greater than that for ordinary investment in Chinese firms.

Stoevsky (2005) applied a model based on Bulgarian firms that is similar to the work of Loof & Heshmati (2006, 2002) both in specifications and variables used. Sensitivity analysis was done by comparing a number of different procedures, such as, with and without selectivity estimation; and with and without the account for the simultaneity. It verified the validity of some of the stylized facts, documented for the developed economies, and the rejection of others using firm-level data for Bulgaria. In line with previous results in the literature, innovation intensity was unrelated to size. Contrary to the findings for the developed economies, the propensity to engage in innovation activities was uncorrelated to size. One of the main results was that it confirmed the validity of the tested model, as the theoretically postulated links were significant and was in the reasonable range, at least for their preferred estimation procedure and specification. Namely, the elasticity of the economic performance measure with respect to the innovation output is significantly positive and in a reasonable range (0.27). But this result emerges only for the no selectivity estimations (both accounting and not for the simultaneity), whereas on taking the selectivity effect into account drives this relation insignificant. On the other hand, the elasticity of the innovation success with respect to innovation intensity was found to be 0.38. Furthermore, the innovation output turned out to be largely unresponsive to business performance. The general conclusion when accounting for both selectivity and simultaneity is that the innovation process is largely unaffected by any business performance measure. The business performance regressors both in levels and in growth rates turned out to be highly insignificant in explaining the innovation propensity, the innovation intensity and the innovative success. The only exception was the significantly positive profitability in growth rate terms in determining the innovation propensity.

The work by Chudnovsky et al. (2006) is on the firms in Argentina. In the first three stages, they also control for differences in the firms' innovation processes (such as interactions and/or cooperation linkages with foreign or domestic government agencies, clients, suppliers, universities, competitors, etc.) using dummy variable, as cooperative linkages are part of the innovation process that might influence the technological behaviour of industrial firms. It reveals that domestic relationships of cooperation do not have a significant impact on the magnitude of the innovation effort (the exceptions are linkages with suppliers and with other firms or consultants). On the other hand, cooperation with different foreign sources seems to have a positive impact on that variable (linkages with foreign suppliers seem to be especially important in this regard). A surprising exception is relationships with foreign clients, which have negative and significant coefficient. It is seen that cooperative linkages have a heterogeneous impact on the innovative output. Interactions with research and training institutions, suppliers and other firms have a significant impact only on the probability of launching new products, but not on the intensity of that activity. Linkages with clients or government have no impact on the innovation output. Finally, linkages with suppliers seem to be the most relevant among the interactions that firms establish for undertaking innovation activities and having innovative outputs.

3.3 Determinants of Innovativeness of Firms

This part discusses the determinants of innovation capabilities at the firm level. Innovation capabilities refer to "the firm's current ability and its future potential to apply firm-specific technology to solve technical problems and/or enhance the technical functioning of its production process and/or its finished products" (Nicholls-Nixon 1995, pg. 7). There is a rich body of literature stressing the overwhelming importance of firm specific factors, on which competitive advantages are built (Hoopes et al 2003; Prahalad & Hamel 1990). A variety of factors, internal and external to the firm contribute to innovation capability. Here, the importance of various resources is brought to light by examining a vast literature and past empirical work.

Empirical studies have substantially informed our understanding of how firms develop valuable resources and capabilities (Henderson & Clark 1990; Clark & Fujimoto 1991; Iansiti & Clark 1994; Hoopes & Postrel 1999), and their subsequent effects on firms' market positions or performance (Collis 1991; Henderson & Cockburn 1994; Hoopes 2001). Firms develop absorptive capability by building knowledge stocks through investment in internal R&D and by creating linkages to external knowledge sources (Henderson & Cockburn 1998). Several external forces are able to stimulate firms to innovate, despite their size and market power, the first of such forces is based on demand factors. Schmookler (1966) first formulated such rationale known as the "demand-pull hypothesis". On the other side, the role of scientific advancements in stimulating industrial innovative efforts, are seen to influence the path and rate of technology advance. The rationale was that advances in science enabled "technology-push" based innovations through the development of new concepts or when incorporated in new machinery and/or inputs, (Rosenberg 1974).

A large body of empirical studies has been accumulated, which emphasize either demand-side variables or technology-related variables as factors influencing firm or industry R&D. Griliches (1990, 1998), Schmookler (1962, 1966), and Scherer (1982), among many others, emphasized demand-side variables, especially market size, showing that inventive activity is responsive to the pull of (the size of) demand, while Scherer (1965), Phillips A. (1966), and Rosenberg (1974), for example, emphasized the importance of underlying scientific knowledge or technological opportunity in explaining firm or industry-level inventive activity. However, as Scherer (1982) pointed out, ''both the pull of demand and differences in technological opportunity, which determine the specific industries in which inventive activity is concentrated, must be taken into account for an adequate conception of how technological change occurs''. The relative opportunities to innovate within a given industry based on scientific progress form the basis for the notion of technology opportunities. Extensive R&D programs and high innovation rates are seen to occur where there is exogenous scientific progress (Phillips A. 1966, 1971), implying that technological opportunity has a positive role. Specifically, the role of basic science is reflected in inter-industry differences in both R&D effort, and innovation output, (Comanor 1967; Scherer 1965; Rosenberg 1974). Moreover, evidence shows that product and process development are not important features of every industry (Pavitt 1984; Karlsson & Olsson 1998). Dosi et al. (1990), distinguish between three main groups of industries: i) supplier-dominated industries in traditional sectors, ii) production-intensive industries with scale economies or specialised suppliers, and iii) science-based industries with knowledge-intensive production. Of these, product and process development are generally not performed at all in supplier-dominated industries while some process development is done in production-intensive industries with scale economies, and are seldom referred to as innovative. The remaining categories, however, have product development as a particularly important feature and are considered as innovative industries.

3.3.1 Internal Resources

In innovation-intensive hi-tech firms, technical knowledge is the main strategic resource to be developed or acquired (Hage & Alter 1997). In-house R&D activities are often perceived as the most effective way to accomplish this (Penrose 1959; Cohendet et al. 1999). R&D activities are very important not only for developing one's own product and process innovations, but also for monitoring competitors and absorbing the latest technological trends on the market (Cohen & Levinthal, 1990; Harabi 1997; Veugelers 1997). Higher levels of in-house R&D activity enable firms to develop heterogeneous resources and learn more about technological opportunities, resulting in higher levels of innovation and economic performance (Freel 2003; Rominj & Albaldejo 2002; Hadjimanolis 2000; Nelson 2000; Oerlemans et al. 1998; Dosi 1988). The knowledge and skills of employees is a valuable asset in innovation processes, as a large part of a firm's knowledge base is embodied in its employees, (Hadjimanolis 2000; Veugelers 1997; Schmookler 1966; Scherer 1965). Larger firms have a variety of knowledge, skills and experiences. Thus firms with larger human knowledge bases (the number of employees dedicated to R&D), have higher performance levels. While strength in "high-tech" depends upon the availability of university trained people, industry more generally requires a supply of literate, numerically competent, people in a wide range of functions outside R&D' (Nelson 2000). Hatch & Dyer (2004) found that human resources are strategically important in semiconductor manufacturing as they embody firm-specific tacit knowledge and that firms that employ effective human resource selection, training and deployment process facilitating learning by doing, enjoy sustainable competitive advantage, (Hitt et al 2001). It is seen that it is vital to develop managerial competencies in the R&D department of firms, due to the increasing availability of innovative competencies on the market.

Internal factors such as past experience of the entrepreneurs and employees, and the stock of knowledge and skills they bring into the firm, enable firms to accumulate capabilities

(Rominj & Albaldejo 2002). Firms' managers are able to develop its absorptive capacity by active internal information provision (Lenox & King 2004). Over time, the capability base of the firm is further enhanced through internal learning, involving investments in formal R&D, making minor adaptations to products, processes and organisation, in-house staff training, and so on. Highly trained workforce is seen to have an advantage in developing, adopting and implementing new technologies (Freel 2005; Gospel 1991).

The presence of R&D departments in firms indicates that research is done more or less on a permanent basis. Kleinknecht & Reijen (1992) verified the positive effect of having a formal R&D department when co-operating with R&D institutes. Veugelers (1997) demonstrated that the effect of co-operation in R&D is not significant in R&D intensity unless companies have an R&D infrastructure. Thus on the one hand, the organisation of in-house R&D activities in a department indicates that the undertaking of these activities is a more routinised and continuous process and that the firm is used to change, which is an inevitable by-product of innovative activities (Meeus & Oerlemans 2000). On the other hand, R&D departments give external partners an identifiable and recognisable unit within an organisation, enabling more efficient knowledge transfer, greater innovation and performance. Especially for SMEs who face specific problems in establishing external linkages, their ability to access external know-how is conditioned by their in-house employment of qualified technical specialists, scientists and engineers (Rothwell & Dodgson 1991). Furthermore, the capacity to go for it alone increases a firm's bargaining power in negotiating with external partners, the licensing fees is seen to be smaller when the receiver firm has a well-developed R&D group (Contractor 1983).

The central proposition of the resource-based approach is that firms select actions that best build on, and maintain their unique set of resources, in order to stay competitive (Combs & Ketchen 1999; Hoopes et al 2003). Previous empirical studies have investigated a wide range of potential factors that might be linked to a firms' innovation propensity, (Symeonidis 1996). It has suggested it is important to control for a firms' export activity (Lefebvre et al. 1998), size (Arvanitis 1997; Karlsson & Olsson 1998), past cash flow and profitability and market structure. Empirical study on Australian panel data suggests that there seems to be no significant association between exports and probability of having undertaken product innovation, (Harris et al. 2001). However, export performance and innovation are likely to be inter-related as well. In general, innovative firms may seek to exploit overseas markets, suggesting that the causality runs from innovation to exports.

Empirical studies have shown that this appears to be the case (Lefebvre et al 1998), although this work suggests a need to carefully control for both the nature of innovation and the type and destination of exports. However, it is also possible that firms that export also have access to improved knowledge flows and, possibly, higher incentives. It is also seen that the exporting activity of firms had a direct impact on their productivity and growth. Knowledge of how to innovate was effectively passed to exporting firms from overseas markets (Hobday 1995).

Rogers (2004) finds that innovation may be higher in exporting firms. Firms with higher management training, firms that network, firms that conduct comparisons with other businesses, and firms that do R&D behave similarly. These results, however, are not consistent across all firm size groups. These results prompt the thought that the process and determinants of innovation may vary across firm size. These empirical studies suggest that small firms participate less in R&D, but at a greater intensity and with a greater productivity once they participate (Vossen & Nooteboom 1996). Also Kleinknecht (2000) and Kleinknecht & Mohnen (2002) found that the propensity to innovate is positively related with size although the relationship may not be linear, and, amongst the innovators, smaller firms tend to have higher shares in innovation sales. The foremost among those associated with the argument that monopoly power and large size spur innovation in firms is Schumpeter (1950), Galbraith (1952) further emphasised the importance of firm size. The literature on determinants of exports are discussed further in chapter 8, on ‘Internationalisation of Hi-tech Firms’ and the literature on the firm size-innovation link is explicitly reviewed in chapter 7 on ‘High Technology Performance’.

3.3.2 External Factors: Innovation or Knowledge Networks

Collaboration can be defined as any activity where two or more partners contribute differential resources and know-how to agreed complementary aims (Dodgson 1993). In this definition the following are included:

1. collaborative research programs or consortia
2. joint ventures and strategic alliances
3. shared R&D and production contracts.

“Both vertical and horizontal linkages are included... direct investment, licensing, marketing agreements and computerised networks and data-banks... are not included as they are essentially one-way transfers of know-how” (Dodgson 1993, pg.13). A vast body of literature has studied the increased importance of R&D collaborations in particular sectors such as biotechnology and information technology, (Nesta & Mangematin 2004; Hagedoorn 2002; George et al. 2001). Rominj & Albaldejo (2002), exploring the determinants of innovation capability in small UK electronics and software firms, stress the key roles played by the (a) regional science base in nurturing high-tech spin-offs, and (b) proximity to suppliers. But in the UK a review done by mostly concentrating on high-tech industries to understand the relationship between innovation and networks has highlighted a number of shortcomings and gaps in the literature, (Pittaway et al. 2004). It highlighted that research across disciplines has been primarily focussing on product innovations, urgent focus is required on the relation between networks and different forms of innovation (e.g. process and organizational innovation, radical versus incremental), facilitating comparison of networking activities across these different types of innovation. The evidence presents the ambiguity of views and considers the debate existing within the literature regarding appropriate network configurations for successful innovation. It points that far more detailed research has to be conducted. Research tends to focus more on the firm's networking activities with suppliers and customers, and less on how diversity of partners facilitates innovation. The role of third parties (professional & trade associations) that are important for the development of informal relationships, the processes through which informal networking relationships develop and subsequently affect innovation, and the mechanisms through which the transfer of tacit knowledge promoting learning are the areas that are under-researched and that needs to be investigated further. Moreover, very limited published research is found on institutional mechanisms facilitating networking and their impact on innovation and the evidence that exists are also mixed in terms of their impact.

Moreover, in the industrial organization literature as well in the management literature, the impact of collaborative R&D on firm's (innovation) performance has remained largely unexplored (Tether 2002; Das & Teng 2000). Management studies have restricted analysis to particular performance indicators in specific industries, e.g. the effect of alliances on high tech start-up firm performance in the biotech industry (Baum et al 2000), the effect of alliance portfolio characteristics and absorptive capacity on biotech firm performance (George et al 2001) or the effect of learning in alliances on market share performance in the global automotive industry (Dussauge et al 2002).

Many from the management domain have looked at the various factors that motivate firms to collaborate (Kohn 1997; Hagedoorn 1993; Nooteboom 1999). Explanations for collaborative R&D that have been extensively discussed revolve around such factors as sharing risks and costs in the face of uncertain technological developments (Das & Teng 2002), shortening innovation cycles, the pursuit of efficiency gains such as economies of scope and scale or synergistic effects through efficient pooling of the firm' resources (Kogut 1988; Das & Teng 2000), learning through monitoring technology and market developments (Roberts & Berry 1985), dealing with regulations and industry standards, and responding to government subsidy policies (Benfratello & Sembenelli 2003; Nakamura 2003). Collaborations may be aimed at acquiring the capabilities they lack, and also as a defensive move, to fend off backward-vertical integration by their large customers. Such customers could easily become rivals who would swallow them up if they were not totally satisfied with the products they receive from these small independent firms (Kohn 1997).

Current research supports the view that network significantly boosts innovation output and the competitiveness of firms in a diverse range of industries (Gemünden et al 1992). Empirical evidence suggests a positive impact of engaging in R&D cooperation on innovation performance i.e. sales of innovative products (e.g. Klomp & van Leeuwen, 2001; Janz et al 2004; Criscuolo and Haskell 2003), patenting (Vanhaverbeke et al 2004), sales growth (Cincera et al 2005), and on the export performance (Chetty & Hamilton 1996). The Porter report (Porter & Ketels 2003) establishes that networking is critical for the development of innovative ability in firms. Powell et al. (1996) argue that in fields of rapid technological change, the locus of innovation is found within networks of inter-organisational relationships. Love & Roper (1999) finds a positive influence of networking. Harris et al (2001) find a significant positive impact of networking on the firm's probability to create product innovations. Where close collaboration already exists, incentive policies can promote the continuance of long-term relationships (Fritsch 2001). Access to networks for prospective entrepreneurs is essential, because they allow access to resources and provide both emotional and business support (Baum et al 2000).

A number of papers have included a cooperation variable in empirical models explaining differences in firm's innovation output (Belderbos et al 2004; Janz et al 2004; Van Leeuwen & Klomp 2001; Klomp & van Leeuwen 2001; Lööf & Heshmati 2002; Monjon & Waelbroeck 2003; Criscuolo & Haskell 2003). Most of these studies use the simultaneous equations approach pioneered by Crépon et al (1998), in which innovative sales levels in turn are allowed to impact on productivity or sales and did not examine systematically differences in impacts across cooperation types. The few papers that have examined the effect of different cooperation types have had ambiguous results, (Monjon & Waelbroeck 2003; Lööf & Heshmati 2002; Van Leeuwen & Klomp 2001). Nesta & Mangematin (2004), analysing the changing contribution of the firms' network to their innovative performance in biotechnology, highlight the relative influence of alliances, according to their aims (research, development and commercialisation) and types of partner, on the innovative performance of the firm for a given phase. The efficiency of collaboration on innovative performance is phase-specific, and behind the apparent complexity of innovation networks, the contribution of different types of partners is linked to the stage of development of the industry and its associated technologies.

In summary, the literature suggests that different types of collaboration may serve different purposes, where the two main goals of innovative effort are cost reduction and market expansion (Reid 1989, ch. 4). Empirical findings support the view that the emergence phase is characterised by a high degree of uncertainty regarding resources, routines, products and the technological environment, (Nesta & Mangematin 2004). Baum et al. (2000) suggest that firms in the emergence phase lack the necessary capital and legitimacy to exchange on the basis of market transactions hence develop external collaboration networks to access capabilities without committing too large a share of firm resources such as research collaborations with academic labs to reach new scientific developments.

Empirical research has shown that in the early phase of product life cycle, innovations come from a narrow range of sources such as, users, suppliers, and from universities (Zucker et al. 1998). The presence of waves of innovations implies that firms must manage a portfolio of collaborations that focus on different waves, according to the development of the technology. It implies that firms must phase their portfolio of collaborations, which includes both research agreements (to explore new scientific solutions) and development collaborations (to better exploit their existing knowledge base), (Nesta & Mangematin 2004). Collaboration with customers is important, as it reduces the risk associated with market introductions of the innovation, particularly when products are novel and complex, and hence require adaptations in use by customers and also to ensure market expansion (von Hippel 1988; Tether 2002; Kristensson et al 2002). In contrast, cooperation with suppliers is often related to the tendency to focus on core business to reduce costs, with outsourcing activities coupled with cooperation on input quality improvements aimed at further cost reductions, (Rominj & Albaldejo 2002).

Cooperation with research is generally aimed at radical breakthrough innovations that may open up entire new markets or market segments (Tether 2002; Monjon & Waelbroeck 2003). Pavitt suggested that in science-based firms process technology is largely developed in-house or sourced from suppliers, whilst product technology is extended internally ‘‘based upon the rapid development of the underlying sciences in universities and elsewhere’’ (Pavitt 1984: 362). Among others, researchers have looked at how firms access knowledge in academic and government labs through professional networks (Cohen et al 2002), competitor alliances (Hagedoorn & Schakenraad 1994; Gulati 1995; Powell et al 1996) and in new ventures through equity investments (Dushnitsky & Lenox 2005a, 2005b). Belderbos et al (2004) studied the effects of different types of R&D cooperation on firm performance for a large sample of Dutch firms. Their findings are that competitor and supplier cooperation focused on incremental innovations, while university and competitor cooperation are instrumental in creating and bringing to market radical innovations, generating sales or products, and improving the growth performance of firms.

There is little evidence to indicate a minimal role of R&D collaboration in the commercial success of innovations, (Negassi 2004). Brouwer & Kleinknecht (1996) also has same conclusions for findings in Netherlands. Love & Roper (2001), modelling UK, German and Irish investment in R&D in manufacturing, find no link. Instead, they find that innovation is more dependent on internal organizational networks. This is also supported by Fischer & Varga (2002) in their study of manufacturing firms in Vienna. Karlsson & Olsson (1998) also finds no association. Harris et al (2000) find that inter-firm networking can facilitate the innovation process, but it will not necessarily lead to innovation success. Tomas & Arias (1995) point out that closely connected networks also entail drawbacks (for example, increasing the complexity of the innovation process, losing ownership control of the innovation and information lop-sidedness) where partners have very different understandings about the nature of agreements. Kohn (1997) in fact reports that, ‘entrepreneurs follow what may appear to be two contradictory strategies at the same time: to insist on establishing wholly owned operations while at the same time structuring alliances. This makes sense if they shun others’ help in those activities that are at the core of their sources of competitive advantage while they seek alliances in the rest of their activities’ (Kohn 1997).

Summarising the above literature there appears to be a broad consensus that networks can foster technological improvement and economic competitiveness through positive externalities, market linkages, and possibilities for collaboration (Albaladejo & Romijn 2000). Interactions with suppliers, customers, public institutions and industry associations may provide missing inputs into the learning process, which the firm itself cannot easily provide. The purpose is to gather information about technologies and markets, and also for obtaining various other inputs to complement the internal learning process, such as external staff training, parts and components, consulting services etc. The geographical network approach to innovation tends to overemphasise an inter-organisational approach to organisational processes like innovation (Oerlemans et al 1998). As a result, there is a propensity to undervalue the contributions made by internal resources (Lenox & King 2004). Yet, in most industries the greater part of innovation effort is made by firms themselves and occurs within firms themselves (Nelson 2000). Moreover, internal resources often act as complements to, or indeed appear to negate the need for, external resources (Freel 2003). Firms require '. . substantial in-house capacities in order to recognize, evaluate, negotiate, and finally adapt the technology potentially available from others' (Dosi 1988, (p. 1132). The interactivity of the innovation process refers to collaborations and iterations involving individuals and departments within the firms as well as, more occasionally, external co-operation with other organisations and institutions (Freel 2002). Rapidly changing technologies and shortening product life cycles, combined with economic and financial uncertainty, are forcing enterprises to innovate through a complementary mix of in-house R&D coupled to the results of R&D performed elsewhere (Link & Tassey 1987). Regardless, "..collaboration, …cannot in any sustainable way be anything but a supplement rather than an alternative to a firm's core method of technology development; internal R&D" (Dodgson 1993, p.164).

3.4 Spatial Proximity and Embeddedness

An important dimension of research regarding innovation is the geographical context in which the innovation process takes place. The economic-geographical or spatial-economic approach stresses the influence of networks of firms and the advantages of (spatial) clustering. Theoretical concepts like the industrial district theory (Marshall 1920; Brusco 1998; Rabellotti 1997), regional innovation systems (Cooke 2001b, 2002a; Cooke et al. 1997; Malecki 1997); innovative milieu (Ayadolt 1986; Cappello 1999; Camagni 1996), and the learning region (Florida 1995; Morgan 1997), link geographically concentrated networks of firms to the innovativeness of these firms. The presence of spatially concentrated mutually supportive networks and interdependence among firms are well documented, in many regions of the world. Case studies of Silicon Valley (Saxenian 1994a. 1994b), Third Italy (Storper 1993) and Baden-Württemberg (Sternberg 1999) are often used to underpin the importance of proximity. However, up till the 1990's, the empirical evidence on the importance of proximity was scarce (Steel industry in England, Allen (1983); SMEs in Italy (Piore & Sabel 1984); Baden-Wuerttemberg in Germany (Herrigel 1993). Although theory and some scarce empirical studies stress the importance of proximity, 'the relevance of proximity is one of the most controversially discussed topics in the context of innovative linkages and networks' (Sternberg 1999). The core of these economic-geographical approaches is the assumption that human interaction and physical proximity are crucial for an optimal transfer of knowledge (Baptista & Swann 1998). Further, it has been suggested in economic network theory, that the effectiveness of such 'learning by interacting' is boosted by regional clustering of the network actors with whom a firm interacts (Keeble & Wilkinson 1999; Cooke et al 1997; Lundvall 1992; Maillat 1995).

3.4.1 Knowledge Spillover and Geography

A central element of theories of innovation is the concept of knowledge spillovers (Cassiman & Veugelers 2002; Gertler & Levitte 2005; Sorenson et al 2006; Audretsch & Stephan 1996). Technological spillovers and other externalities are central to the argument for a geographical clustering of innovation (Caniels & Rominj 2003; Jaffe et al 1993; Rogers E.M. 1996; Prevezer 2001). The spatial concentration of innovative activity is argued to be attributable to factors related to technological external economies, as distinct from factors leading to the concentration of production (Audretsch & Feldman 1996). Griliches (1979, 1992) distinguishes two kinds of spillovers: rent spillovers and (pure) knowledge spillovers. Rent spillovers arise when quality improvements by a supplier are not fully translated into higher prices for the buyers. Productivity gains are then recorded in a different firm or industry than the one that generated the productivity gains in the first place. Rent spillovers occur in input-output relations. Pure knowledge spillovers involve benefits of innovative activities of one firm that accrue to another without following market transactions. By and large, the findings suggest that cooperation is induced by knowledge spillovers and this in turn leads to higher R&D investment levels.

Empirical studies for the United States stress the importance of proximity (Zucker et al. 1998a; Jaffe et al 1993; Feldman 1994; Audretsch & Feldman 1996; Almeida & Kogut 1995, 1997). Zucker et al. (1998a) finds that the firms' number of new product development is positively and significantly related to the number of university stars in their geographical area. Niosi (2000b) finds that local links are increasingly seen as being especially critical for developing basic research and for creating a critical mass of research capability (Cooke 2002a). Jaffe et al (1993) compare the geographic localization of patent citations with that of the cited patents, as evidence of the extent to which knowledge spillovers are geographically localized. They find that, although localization slowly fades over time, a US patent tends to be cited more frequently within the state in which it was filed than outside the state. Feldman (1994) finds that product innovations exhibit a pronounced tendency to cluster geographically, and that the geographic clustering of product innovations at the state level is related to the level of industrial R&D and university R&D expenditures in the state, which is consistent with earlier findings of Jaffe (1989). Audretsch & Feldman (1996) find that 'even after controlling for the concentration of production- industries in which knowledge spillovers are more prevalent - that is where industry R&D, university research and skilled labour are the most important - have greater propensity to cluster than industries where knowledge externalities are less important'. They conclude that while the cost of transmitting information may be increasingly invariant to distance, presumably the cost of transmitting tacit knowledge rises with distance.

Marshall (1920) and Krugman (1991) argue that geography may matter because of tacit knowledge, that is vague and difficult to codify, (as compared to codified knowledge or information), as there is the advantage of allowing the recipient of the knowledge to query the originator when attempting to correct errors in their initial understanding (Sorenson et al. 2006). The marginal cost of transmitting information or codified knowledge across geographic space fall under the influence of new developments in information and communication technology whereas the marginal cost of transmitting tacit knowledge rises with distance (Audretsch 1998). As tacit knowledge and human interaction become more valuable in the innovation process, geographical proximity becomes crucial to the innovation process. Moreover the exchange of tacit knowledge may require a high degree of mutual trust, understanding, a common language, shared norms and values, such that proximity may play an important role in this context, (Maskell et al 1998; Nooteboom 1999). Lawson & Lorenz (1999) explicitly link tacit knowledge to regional competitive advantage.

Empirical findings confirm that local venture capital (VC) ties provide key inputs, both the investment capital and the entrepreneurial and managerial know-how necessary for commercial success of innovation (Gertler & Levitte 2005; Zucker et al., 1998b; Niosi 2000b; Cooke, 2001b; Powell et al. 2002). Some of the factors identified as increasing innovative activity are those of spillovers across industries, spillovers of university research, the presence of related industries and specialised business services (Gertler & Levitte 2005; Caneils & Rominj 2001; Feldman 1994; Jaffe 1986; Baptista & Swann 1998). Studies by Audretsch & Feldman (1996), and Jaffe et al. (1993) imply, that geographic proximity matters when knowledge spillovers are informal. Audretsch & Stephan (1996) concludes that when knowledge is tramsmitted through formal ties between researchers and firms, geographic proximity is not necessary, since face to face contact does not occur by chance but instead is carefully planned. Moreover, Karlsson & Olsson (1998) suggests that it is not necessary to be located inside the cluster to be innovative. SMEs can be early users of new technology even if they are located outside the cluster. Beugelsdijk & Cornet (2001) do not find evidence that proximity matters for spillovers in the Netherlands, but do find evidence that presence of a technology university is positively related to innovativeness. Oerlemans et al (1998, 2001) concludes that innovative relations with local buyers and suppliers are just as knowledge intensive as relations with buyers and suppliers located outside, for manufacturing firms in Netherlands. However, it is seen that spatial pattern of innovation in any industry would be more concentrated the more tacit and complex the relevant knowledge for that industry and so particularly for pharmaceutical, chemical, electrical and electronic industrial sectors (Breschi 1997; Audretsch & Feldman 1996).

3.5 Conclusion

This chapter provides insights into the literature on the theoretical and empirical background to this research on high technology, innovation, networks and performance. It brings together those different theoretical concepts, and related empirical and econometric work, that have laid the foundations of this research. It started with the review of research on R&D, innovation and productivity studies. The Cobb-Douglas production function, the knowledge production functions, the CDM model were discussed, as the econometric model (chapter10) of this thesis has evolved from these. Topics on the determinants of innovation, the importance of internal resources as compared to external resources that firms seek to internalise for innovation, and its competitiveness, were reviewed in detail. The significant role of different external collaborations and the importance of various knowledge spillovers were brought to light by exploring a variety of empirical research from the recent past. This research aims to achieve a balance in addressing these issues.

Chapter 4 The Emergence of High Technology in the Scottish Economy

4.1 Introduction

High technology is of great significance to policy-makers worldwide, due to its association with the 'knowledge-based economy' and is often perceived as an engine for growth. Its potential to reposition national and regional economies competitively has encouraged a range of policies and initiatives on hi-tech sectors in the national governments, regional, and local economic development agencies, particularly in Scotland (SE 2005, 1998). This chapter presents a detailed review of past and present policies and structural features of Scottish high technology.

Scotland has always been a place of technological excellence and home to some of the most technically advanced companies in the world. However, its status is constantly under threat (Scottish Economic Report 2004). The economic challenges facing Scotland today arise from new low cost locations like China and new EU members, the shortening product lifecycle, and globalisation of markets for high value skills and knowledge. Its consequences include the relocation of corporate investors to new low-cost regions, the drying-up of investment in large-scale manufacturing, and the under utilisation of highly skilled staff and infrastructure. In the wake of this, Scottish Enterprise (SE) has shifted its focus to the creation of high value investment opportunities, upgrading by moving higher up the value chain and stimulating research in world-class technologies. The present SE strategy of a 'Smart, Successful, Scotland' (SSS) reflects a qualitative shift of strategies from one emphasising inward investment (on the basis of low-cost advantages, low value-added and labour intensive activity) to one emphasising productivity, competitiveness and innovation (SE 2001).

This chapter provides a perspective on the significant changes that have occurred in the Scottish high technology landscape, emphasising on its transition over the period of the SDA (Scottish Development Agency) and then SE. In particular, it examines the transition from electronics to semiconductors, and subsequently from the microelectronics and optoelectronics cluster strategies, to the present 'Single Strategy for Micro & Optoelectronics' (Micro-Opto Electronics Cluster Review & Strategy, SE 2005). Section 4.2 examines the roots of high technology in the Scottish Economy (Brown et al. 1999), the subsequent de-industrialisation followed by the regeneration strategy of 1970's, the long presence of various MNC branch plants in Scotland (Turok 1997; Botham 1997; Walker 1987), and the industry policy adopted by the SDA, (Rich 1983). The extent of embeddedness of Silicon Glen is also reviewed. Section 4.3 discusses the identification of hi-tech clusters in the light of the DTI's industry policy on knowledge-based economy. Section 4.4 reviews the SE initiatives on high technology in the wake of the 'SSS' strategy. Section 4.5 provides an overview of the current hi-tech structure in Scotland, thus explaining the rationale behind the selection of the 5 hi-tech sectors of life science, optoelectronics, microelectronics, digital media and software for the research of this thesis.

4.2 Silicon Glen and the Evolution of Electronics FDI in Scotland

Silicon Glen is identified with the industrial central belt of Scotland, which has a concentration of technology companies, right across the 70 km stretch between Scotland's two main cities, (Edinburgh and Glasgow). It is now home to over 150 specialist companies directly involved in communication technologies, and about 400 microelectronics and optoelectronics companies. Added to that are host of other companies involved in every aspect of subcontract and support for the industry. Semiconductor, optoelectronics, microelectronics and software industries together support an entire electronics sector employing over 83,000. New start-up companies, university spin-offs and firms relocating to Scotland, are continually rejuvenating the sector.

4.2.1 Roots of Electronics FDI in Silicon Glen

Scotland can trace its electronic roots back over half a century. Barr and Stroud (now Thales) and Ferranti (now BAE Systems) were formed in the 40's. Since then a host of companies have located in Scotland, leading to a phenomenal growth in the sector. Silicon Glen is where the critical mass of electronics and supply companies was established as a result of foreign investment. That took place in several phases (Baggott 1985a).

First Phase (1945-1959)- The first phase of inward investment that occurred during the immediate post-war period mainly involved American firms, (Brown et al. 1999). Given the weak state of Europe's indigenous producers in these product markets, European market access was one of its main attractions. Firms manufacturing electro-mechanical products, like clocks, typewriters, cash registers and first generation computers were the first to establish plants: NCR in 1947, Honeywell in 1948, Burroughs in 1948, Polaroid in 1950, IBM in 1951.

Second Phase (1960-1975)- The second phase witnessed the emergence of a microelectronic components sector. A raft of firms like Motorola, General Instruments, Hughes Microelectronics, HP and National Semiconductor arrived in Scotland. National Semiconductor and Motorola engaged in mass production of standard integrated circuits, whilst Hughes and General Instrument manufactured specialised 'chips' for defence applications. Thus the onset of semiconductor production gave rise to the term 'Silicon Glen', to denote the cluster of firms in Scotland's central belt. A number of factors attracted foreign-owned firms to locating in Scotland. National factors were: market access to the UK and to Europe; and labour market regulations. Regional factors were: the human, intellectual and educational infrastructure; a quality electronics supplier-base; the track record of existing overseas companies; physical infrastructure; and also the significant role played by Scotland's inward investment and other economic development agencies. It included Locate in Scotland (LiS) for inward investment; and the Scottish Trade International for exports (Hood 1991). However, these initial periods of investment were followed by a period of retrenchment during the early to mid-1970s, which saw the levels of employment in the sector diminish, due to some divestments. The unemployment rate in Scotland was fifty percent above the British average, when the SDA was established in 1975. The British government undertook this initiative following extensive debate on the need for a development agency to tackle the decline of industries, and other problems such as social, urban, rural, environmental underdevelopment.

Third Phase (1976-1985)- The SDA's main objective was long-term economic regeneration through industrial and environmental programs. It pursued an aggressive investment policy of industrial investment to enhance Scotland's international competitiveness. The SDA invested a major portion of its budget to fund SME in risky ventures with growth potential, and to support commercial exploitation of research in 1977 and 1978. However, the SDA was unsuccessful in this strategy, due to the high failure rate of the SMEs, and many nonviable projects. As a result, the investments were drastically reduced in 1981. The SDA restructured its programs in a major way following this. Its investments strategy shifted to arranging joint funding with the private sector, acting as a guarantor for private investment, and also as a liaison influence between business and potential investors. It played a significant role in promoting small firms. Foreign inward investment was extensively promoted, mainly of hi-tech firms from Japan, the USA and Western Europe. The SDA shifted away from funding traditional industries, to funding hi-tech industries like electronics (Rich 1983). While the traditional industries were predominantly indigenously owned and controlled, these new industries were developed through inward-investment, and were characteristically branch-plants of multinationals.

The SDA strategy on hi-tech industries was launched in 1979. It subsequently developed and identified those industries in which Scotland had a firm base, strength and growth prospects (e.g., medical equipment, pharmaceuticals, biotechnology, energy related industries and advanced production engineering). The highest priority was given to the electronics industry, with its strengths in semiconductors, industrial equipment, and information systems and defence. LiS was highly successful in leveraging state and EU funds to attract manufacturing and assembly work from major multinationals to the central belt of Scotland. It generated a substantial number of medium to low value jobs in high unemployment areas. By 1980, there were 275 foreign owned plants, 70% of which were US owned, accounting for about one-fifth of total employment in Scottish industry. In 1982 alone, 32 foreign firms as well as 25 English firms moved to SDA premises. This generated a turnover of £234 million and a substantial increase in employment. The third wave saw a broader array of firms like, Burr- Brown and Digital Equipment, coming to Scotland, but most notable of all were the arrival of Japanese firms: Mitsubishi Electric in 1978; Oki in 1979; NEC in 1980; and JVC in 1985.

Fourth Phase (1986-) - The fourth wave of inward investment started in the mid-1980s, when firms in the data processing sector and manufacturers of personal computer, such as Compaq and Sun, moved to Scotland during the late-1980s. The SE that was formed in April 1991 further expanded the work carried on by the SDA. A variety of other consumer electronics and telecommunications firms also arrived, such as Motorola in 1992. Further, large investments were made by, Taiwanese and Korean expanding into Western European markets by locating in Scotland. This FDI activity broadened the overall profile of Scotland's electronics industry, creating a greater emphasis on consumer electronics and computer peripherals. The electronics gross output in Scotland increased fourfold during the 1980s. This implies a very substantial compound growth rate of 14% per annum, whilst the rest of manufacturing experienced stagnation. By 1990 electronics had become a sizeable part of the Scottish economy, accounting for 20% of gross manufacturing output and 42% of manufactured exports (Turok 1993a). Nearly half of all UK exports of computers and peripheral equipment, originated in Scotland. Between 1989 and 1997 electronics accounted for about two-thirds of all inward investments, as shown in the Table 4.1.

Table 4.1 Inward Investment in Scotland (£ million, 1990 prices)

	1989-91	1991-93	1993-95	1995-97
Total inward	1,240.4	682.4	1,386.5	3,158.5
Total non-UK	842.7	576.3	1,268.9	2,941.1
Electronics	810.5	290.3	930.3	2,540.7
Electronics as % of total inward	65.3 %	42.5 %	67.1 %	80.4 %

(Source: Locate in Scotland)

The Scottish electronics industry in 2004 had 43,000 employed, and contributed 14% to the Scottish GDP. It accounted for 12% of Scotland's manufacturing employment, and more than 50% of its exports. There are 158 foreign owned electronics firms in Scotland today. Table 4.2 provides relevant figures on the value of investments, the number of projects and the jobs created over the 5 years (1998-2003).

Table 4.2 Investments, Jobs & Projects between 1998-2003

Year	Projects	Jobs	Investments (£ millions)
1998-1999	78	10867	761.20
1999-2000	91	19334	650.10
2000-2001	102	14346	1763.30
2001-2002	59	6386	272.20
2002-2003	57	7159	205.20

4.2.2 Embeddeddness of the Electronics FDI in Silicon Glen

While electronics FDI has been associated with a range of positive effects (mainly income and employment), it has been accompanied by concerns over their level of 'embeddedness' within the Scottish economy. Evidence from the various studies, on the scale and nature of linkages in the Scottish electronics industry has been consistent, in finding that FDI plants transferred very little to the local economy (Botham 1997; Dunford 1989; MacGee 1982). In contrast to the spectacular growth of electronics sales and gross output, there has been only a modest rise in actual production and employment in electronics (Turok 1993). Gross output increased at a compound rate of 16% per annum between 1983 and 1989, compared with 7.1% for value added and only 1.8% for employment. Gross output, a preferred indicator of official sources, is a measure of company sales, and not of production. Value added is a better guide to the amount of work done by firms in Scotland to develop and manufacture the products sold, and is also an indicator of the income generated locally (i.e. sales value of firm's output less the cost of materials/services bought from other firms and government bodies). The share of value added in gross output was only 24.2% in electronics in 1989, compared with 34% in the rest of manufacturing. Furthermore, it had fallen steadily from 39.2% in 1983. A big difference existed between UK-owned and foreign-owned shares of value added, with the latter falling faster, and from a lower starting point in 1983. The widening gap indicated the rapid growth in electronic products shipped from Scotland, but slower growth in the amount of actual production, with less value added as sales increased, and more materials, components & services bought in.

In terms of local purchasing, only 22% of total purchases were made within Scotland. The Scottish firms supplied lower value-added components to the major investor plants such as packaging and sheet metal presswork (Jackson & Patel 1996). Turok (1993) noted that only 12% of the sector's material inputs were sourced locally. The higher value-added functions of companies, notably strategic management, research and marketing, had consistently been located outside Scotland. Only a limited number of firms undertook sophisticated design work in Scotland, with the majority remaining primarily geared towards high-volume assembly (Clarke & Beaney 1993). Haug et al. (1983) in commenting on Scotland's electronics during the early 1980s noted that most development work was of a process rather than a product nature. Subsequent evidence suggested that relatively more design was being undertaken in Scottish branch plants (Young et al. 1988). The major investments had been assembly plants, with the attributes of low levels of technology transfer, and weak linkages to local suppliers (Botham 1997). The nature and range of the skills and technical expertise inherent within Scotland's electronics plants was not high end, a considerable degree of skill polarisation existed within the industry (Dunford 1989).

The challenges in electronics were many, including limited local ownership, limited research activity in firms, and limited linkages and embeddeddness (MacGee 1982). In short, Scotland's indigenous electronics industry did not grow greatly in response to the demand of the major electronics investors. Technological weaknesses of indigenous firms, questionable quality and reliability of these firms, and their relatively high prices for some products were some of the adverse factors. Other adverse factors included the branch-plant character of many foreign firms, like absence of strong product design and procurement functions locally, and their protected supply relationships with their parent corporations or global suppliers.

4.3 DTI Cluster Classification applied to Scotland

As part of the development of DTI's industry policy emphasizing knowledge-based industry, several white papers were produced since 1997.

- 'Our Competitive Future – Building a Knowledge Driven Economy' (1998)
- 'Excellence & Opportunity–A Science & Innovation Policy for the 21st Century' (2000)
- 'Opportunity for All in a World of Change –Enterprise, Skills & Innovation' (2001)
- 'UK competitiveness: Moving to the Next Stage' (Porter & Ketels 2003)
- 'Competing in the Global Economy: The Innovation Challenge' (DTI 2003).

In the light of the 'Competitiveness White Paper' in 1998, the UK government committed to investigating the concept of clusters. The main purpose was to help the regional development agencies (RDA) to carry on with their important work on clusters. It highlighted the fact that business development is often strongest when firms cluster together, creating a critical mass of growth, collaboration, competition and opportunities for investment and knowledge sharing (DTI 1998). In November 1999, Lord Sainsbury formulated two initiatives, first was the establishment of a Cluster Policy Steering Group drawing together the RDAs, academia, local government, the private sector and other cluster experts, to identify barriers to the growth and development of clusters, and to develop appropriate policy solutions.

The second was a research project to map existing cluster activity in the UK, undertaken by Trends Business Research. The Clusters Policy Steering Group adopted the Trends Business Research report "Business Clusters in the UK- A First Assessment" (DTI 2000a). The objective was to draw up a detailed systematic inventory of existing clusters across all sectors of the UK economy. Specifically, it aimed to identify what clusters existed and to map them on a nationwide basis, at the same time detailing their geographical distribution, region by region. It identified 154 clusters across a wide range of sectors/technologies in both the manufacturing and service industries, including the 13 clusters in Scotland. It concluded that not all 154 cases were targets for cluster development policies, as on closer examination many were actually concentrations of industries rather than clusters.

4.3.1 National and Regional Cluster classification by the DTI

In identifying clusters across the UK, their scale and significance was central to the analysis. Comparative scale- size of a cluster was considered in relation to the relevant sector(s) nationally, and the significance- size of a cluster was considered in relation to the regional economy in which it is located. Thus a 'cluster' in a particular sector or group of interrelated sectors may be deemed significant at the regional level in terms of its share of regional employment, but in national terms need not be significant, because it represented a small proportion of national employment. This raised the issue of 'national clusters' and 'regional clusters'. Initial assessment of the identified clusters was according to the following criteria: (DTI 2001).

Stage of development, 3-way classification and assessment was based on regional discussion, the growth pattern and judgement. The intention was to suggest the possibility of growth along the lines of a 'life cycle'.

- Embryonic - Small in relation to UK
- Established - Functioning, or could do so with potential for future growth & entry
- Mature - Cluster probably as 'full' as it likely to get, entry difficult.

Cluster Depth, a two-way classification and assessment of cluster depth was based on the mix and range of industries present within the identified cluster.

- Deep - Cluster made up of a considerable number of components (institutions)
- Shallow - Opposite

Significance- The cluster's regional, national or international significance was assessed based on regional discussion, analysis of the UK's globally competitive industries, and judgement.

- Internationally Significant - Containing internationally competitive industries.
- Nationally Significant - Large but concerned with domestic markets
- Regionally Significant - Local concentration

Employment Dynamics based on an estimate of employment growth, characterised as 'growing', 'declining' or 'stable', based on job growth between 1991 and 1998.

Nature of cluster links had the following categories: links formed based on input-output table; links based on shared knowledge; and markets.

Unique Clusters -Alongside clusters that are distributed across the UK, there were also unique clusters that appeared in one place only, or were of a different nature and scale to similarly named clusters found elsewhere.

Non SIC-based clusters - The DTI found that the SIC codes do not capture all the industries and complexities involved in clusters. Identifying 'less than obvious' clusters depended on local knowledge, and information from the regions. In addition Dun and Bradstreet data was used extensively to identify 'non-SIC' based clusters. Optoelectronics, biotechnology, environmental services, tele/direct marketing, marine engineering, and R&D activity were the main non-sic based clusters.

In Scotland, optoelectronics, biotechnology, ICT, and creative industry were the technology clusters that were identified by the DTI cluster mapping exercise. The DTI classified the Scottish optoelectronics cluster as a unique, embryonic cluster, and the biotechnology cluster as embryonic, shallow, growing and international. The ICT cluster was characterised as established, shallow, growing and international; and the creative industry cluster as established, shallow, growing and national.

4.4 Evolution of Scottish Technology Clusters in the light of SE Cluster Policies

Scotland already had its cluster policy in place in the early 1990's, much before the initiation of the DTI cluster strategies in 1998. The SE approach was to build upon previously successful sectoral initiatives, which were largely state-led and interventionist (see section 4.2). Porter's concept (Porter 1990) was used as a starting point to undertake cluster development, but this theoretical framework was not the only tool, (Lagendijk 1999a; Bergman & Feser 1999). SE was flexible in its approach by accommodating varying industrial, market, institutional, and political conditions. Moreover, the geographic boundaries of clusters were set flexibly. Thus market forces, and the infrastructure characteristics inherent in each cluster, determined those boundaries (SE 2002a).

First Wave- The ‘Company Monitor’ in 1993 identified 12-15 industries that were ‘ripe’ for clustering. No real agreement was reached until 1997, when a pilot cluster-based program was introduced, determined by the ability of clusters to compete globally, in respect of semi-conductors, food and drink, biotechnology and oil and gas. SE overlaid the Monitor’s work with some of their own criteria, such as overall growth potential and the level of industry support, to identify the industries. In this process the Oil and Gas was dropped, as it was realized that the time was not right to progress it. Thus the SE priority projects were biotechnology, semiconductors and food and drink. Table 4.3 shows the characteristics of pilot clusters, (Enright 2000).

Table 4.3 A Typology of Scotland’s Pilot Clusters

Cluster Characteristics	*Biotechnology*	*Semiconductor*	*Food & Drink*
Origin of Industrial Base	Organic	Transplant	Organic
Geographic Scope	Dispersed	Localised	Disperse
No. /Size & Importance of Firms	Sparse	Sparse	Dense
Breadth	Broad	Narrow	Broad
Depth	Shallow	Shallow	Deep
Overall State of Cluster	Potential	Policy-Driven	Latent
Development	High	Low	Low
Innovation Capacity	All ring, no core	All core, no ring	All ring, no core
Cluster Governance	(Research-led)	(MNE-led)	(SME-led)
Coordinating Mechanisms	Public-Private, BioAlliance	SE initially	SE initially

Source: Brown (2000)

Although the clusters were originally identified using Porter’s Diamond, the SE was quick to devise new strategies in the light of the lessons learned from the first wave of cluster initiatives. It highlighted the fragmentation that existed between national policy makers and local delivery organisations such as Local Enterprise Companies, Enterprise Trusts, Chambers of Commerce and Local Authorities. Recognising the cyclic nature of the semi-conductor industry, such as the migration of assembly jobs from Scotland to other countries, LiS put significant efforts into attracting high-value R&D to Scotland, so as to strengthen linkages in the local value chain. Relocating an assembly plant to a region with a lower wage structure is a relatively simple exercise, but to move an entire value chain is much harder, thus making any decisions to decant operations from Scotland less attractive, in turn reducing the risk of severe and sudden job loss. Moreover, the lack of influence of local managers, when the key decision makers are outside the cluster, was recognised from the previous sectoral initiatives.

Second Wave- In 1999 SE initiated a second wave focussing on industries where future competitive advantage might lie, and identified creative industries, forestry, optoelectronics and tourism. They focussed on macro-economic growth, network connections, goal alignment and influencing capabilities of SE. This resulted in more effective selection. Ranking on a scale of 'Very / Moderately / Not Suitable' was done for each, as a priority cluster initiative (Brown 2000). £38 million was allocated over 4 years for biotechnology, £46 million over 4 years for semiconductors, plus tourism, food & drink, as well as 4 other cluster agendas. The 'Microelectronics and Optoelectronics cluster strategies' were launched in 1999 and 2000, and began by mapping the cluster, the core and related industries and the linkages between actors. This provided an overall framework to allow any interventions to be targeted much more effectively, and a context for local delivery organisations to work with the actors at micro-level. Clustering was adopted for setting a meso-economic framework to direct micro-economic promotion and intervention with groups of firms, rather than individually, (SE 2002a, Partners in Development). Scottish Development International, a joint venture between the Scottish Executive and SE was created to integrate Scotland's international economic development activities, (created by merging complementary activities of the former Scottish Trade International & LiS). Initiatives in the micro and optoelectronics cluster were:

- The Scottish Microelectronics Centre offering hi-tech incubator facilities to foster company growth in microelectronics.
- Compound Semiconductors Ltd. for the commercialisation of research in optical semiconductors by providing a pooling of advanced compound substrate facilities, developing processes and technologies to a high level, for transfer to industry.
- Amcet Ltd. a government-academia commercial partnership to develop and exploit advanced material technologies in microelectronics, geared towards industry collaboration and the development of applications for the technology.
- Optocap providing packaging services to universities and start-up companies in optoelectronics, microelectronics, nanotechnology, micro displays, sensors etc.
- The Alba Centre created to promote electronic design, to ensure an adequate supply

of highly skilled manpower to sustain the cluster. Four universities were in partnership to offer the first System Level Integration masters course that concentrate on the process of system-on-chip design and the use of intellectual property.

These initiatives spearheaded the growth and development of the industry from a very low base to one generating an international reputation for sophisticated microelectronics design and related technologies. It led the way for joint initiative between government, local agencies and academia, and thus stopped agencies from having to act in isolation. Other clusters such as the Food & Drink and Biotechnology began to embed this approach. Raines (2000) reports on research on cluster initiatives in several European countries, and notes that Scotland now recognises clusters according to the following typology:

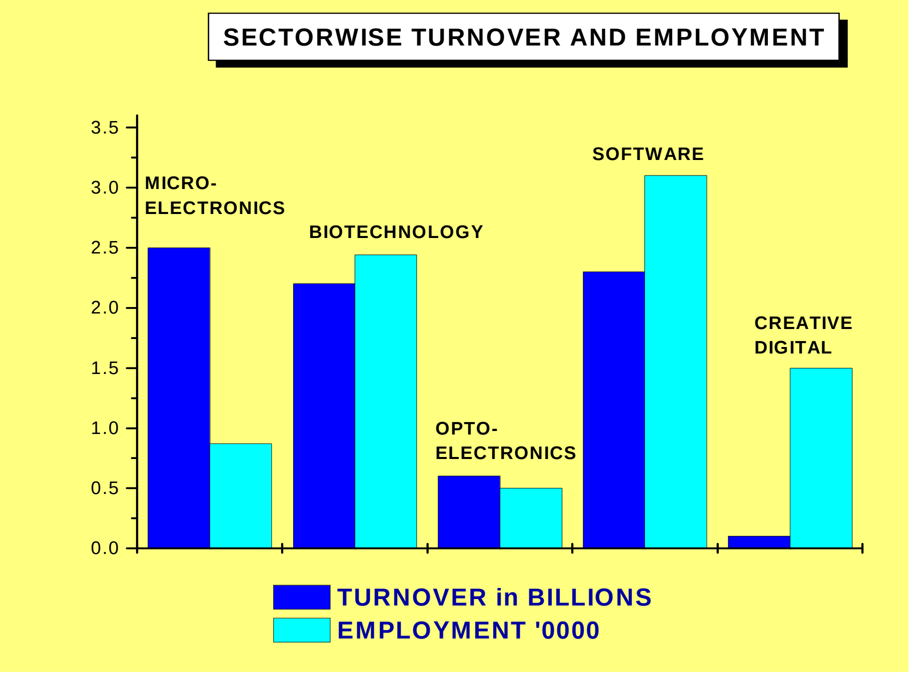
- Value-chain clusters- delimited by a network of supply linkages
- Competence-based clusters- based on the technological expertise in a region
- Functionality-based clusters- cutting across industry boundaries along issues such as knowledge and knowledge management.

SE's recent cluster initiatives whilst developed in a top-down fashion were also based on extensive consultation with the actors in the marketplace. The scope of clusters was extended to hybrid clusters e.g. cutting across boundaries. The Creative Industries cluster is an example of a functional/value-chain hybrid cluster. It unites a number of traditionally disparate sectors via a common function i.e. design capability. Various sectors such as architecture, games software, arts & culture, multimedia, advertising, publishing, TV & radio, music and film now share design expertise through a process of co-creation. 'Interactive Tayside' was created with the objective of developing and nurturing the indigenous creative digital media industry in Tayside. Policy support for cluster is time-boxed, ensuring that funding mechanisms and industry-led bodies are in place, to continue any further action needed. The formation of key industry groups is fundamental for the continued growth and co-creation within these industries once public-sector involvement ceases, (e.g. Scottish Screen & Scottish Games, in Creative Industry). The more recent cluster initiatives relate to financial services, chemicals, textiles, aerospace and eLearning.

4.5 The Current High Technology Structure in Scotland

In this section, by reviewing the clusters of optoelectronics, microelectronics, digital media, software and life science, the current Scottish high technology setting, their strengths and weakness, are revealed. A review of the five individual hi-tech clusters, their strength and potential, their components and interaction, distribution by location, age, size & technology represented will be considered one by one, (see figure 4.1). The selection of these five clusters is in accordance with the SE strategy on key technology clusters (refer section 4.4; chapter 1, section 1.5.2; chapter 2, section 2.4 for details).

Figure 4.1 Comparison of the Five Sectors (2003 Figures)



4.5.1 The Optoelectronics and Microelectronics cluster

Since the launch of the Microelectronics and Optoelectronics cluster strategies in 1999 and 2000, there has been radical changes, both internally in the industrial organisation and externally in the global marketplace. Microelectronics and optoelectronics industries in Scotland have grown and matured since then. The introduction of key initiatives such as the ‘Proof of Concept Fund’, the ‘Scottish Co-Investment Fund’ and the ‘Intermediary Technology Institutes’ and initiatives such as the Alba Centre, Optocap, Compound Semiconductor Technologies and the Scottish Microelectronics Centre (SMC), collectively have provided vital support for companies such as MED, Critical Blue, Ice Robotics, Cadence, Epson, Motorola, Intense and Point 35. Progress has been made in many areas, and companies have survived and developed despite the closure of facilities along with restricted growth in the electronics design sector, coupled with the rise and subsequent fall in telecommunications markets, slow down in the investment landscape and a virtual halt in inward investment activity. Companies such as Picsel, Abelon Systems, Nallatech, 4i2i, Optos, Polaroid, Mentor Graphics, Edinburgh Instruments, Linn, Nallatech, BAE Systems, Bitwise, Freescale Semiconductor, Photonic Materials, Axeon, Xilinx, Coherent, JVC, National Semiconductor and ST Microelectronics all continue to thrive. The highlights of the cluster are the following:

- A complete Scottish supply-chain for diode pumped solid state lasers for defence and other applications is now in place, five years ahead of schedule.
- The industry celebrated its first listing in four years with the successful initial public offering for Wolfson Microelectronics.
- The number of indigenous design companies has more than doubled, and the number of designers engaged in R&D is nearly 2000, a rise of nearly two thirds.
- The Institute for System Level Integration (ISLI) has become the largest dedicated system on chip centre in the UK. The launch of the world's first MSc in ‘System Level Integration’ in 1999 and its leading engineering doctorate in 2000.
- Microelectronics, Optoelectronics and Communications Technologies have been awarded over a third of all Enterprise Fellowships. Over £5.7m of Proof of Concept funding has been awarded to projects in these areas.

Today the microelectronics and optoelectronics cluster has over 360 companies, 380 principal academics, 150 research groups and 14 centres for technology transfer. It employs over 25,000 people, retaining some of the most talented personnel and contributing over £1.1 billion to Scotland’s gross value added. Both remain key sectors for Scotland. The cluster is home to both a number of the world’s leading companies and to the most innovative and dynamic Scottish start-ups, (www.scottish-enterprise.com/sedotcomhome/microelectronics). In the microelectronics cluster alone 2300 are employed in semiconductor fabrication, 1800 in supply and around 1000 in electronics design. Overall, over 200 companies employ more than 6000 people in microelectronics. The semiconductor fabricators contribute to 1% of Scottish GDP mainly, by selling into export markets, and they site around a quarter of their global production in Scotland. However, Scotland has no plants from the market leader Intel or any other firms in the top 20. Two other Scottish fabrication plants, Semefab, Hughes (Raytheon) are very small firms indeed in the context of the global semiconductor industry, and make up only 10% of Scottish activity. None of the European manufacturers make chips in Scotland.

Across the global economy, the typical Scottish industry has a share of approximately 0.3% of global markets. Scotland is a world centre of product design and system level integration technology. Scotland has expertise in device-modelling, III-V semiconductors organometallics, ultrafast systems, MEMs, and silicon microfabrication, (www.scottishdevelopmentinternational.com).

The optoelectronics cluster has more than 90 companies involved. Most of them manufacturing their own products and exporting over 65% of their output, and 99% of sales are own company products. The total annual turnover is £800million, and there are 90 firms having 20% annual growth rate. There are 13 universities engaged in optoelectronics from which 550 students graduate with specialising in optoelectronics, and employ over 450 researchers. Scottish researchers are the 7th most quoted in the world and this growing industrial sector is currently valued at around £800 million, employing over 4200 people. With only 10% of the UK's population, 34% of UK government optoelectronics research funding goes directly into 20 Scottish University departments. Scottish universities conduct a range of optoelectronics research, and their notable strengths are in semiconductor materials, optoelectronic devices, optical information processing and diode pumped solid-state lasers.

4.5.2 Life Science (Biotechnology) Cluster

Scotland is home to one of the most sizeable life science clusters in Europe and has a significant multinational presence in both R&D and in manufacturing. Scotland's life sciences community has had an average growth rate per annum of more than 20% during the period 1999-2003, (www.scottishdevelopmentinternational.com). As of October 2004, in this cluster there were over 570 organisations employing more than 28,000 people. 80% of this is located within a 50-mile radius of the cities of Edinburgh, Dundee and Glasgow. Annual turnover is £1.38bn, and employment is 28000. Expenditure by SE has involved £38 million over 4 years in respect of the biotechnology cluster. This is spent mostly on the infrastructure associated with science parks and incubators, and also on skills training and incentives for new entrants.

Scotland’s strength range from nuclear transfer discoveries like Dolly the sheep to bioinformatic, through drug discovery and development, stem cell research, pharma support and biomanufacturing, contract research organisations as well as a growing medical device sector. Scotland’s primary focus is on human healthcare: 71% of the core life science organisations are involved in this aspect. The Agricultural Biology-12%, Environment- 9% and Veterinary developments- 8% make up the remaining 29% in life sciences cluster. There are 98 biotechnology firms in the Life Science cluster employing 3897. Scotland accounts for 17% of UK biotech graduates and 18% biotech related PhDs. Scotland is home to several bio-sector companies. Major players are Glaxo Smithkline, Roche, Quintiles, Bioreliance, Cyclacel, Strakan. It is one of the fastest growing regions for new start-ups and has 21% of UK's biotech firms. The various factors making this possible are: the very strong science base, commercialisation by university & research institutes, infrastructure - incubators & science parks creation, skilled workforce, early stage financing, the creation of national & international network, local networking initiatives, pre-start-up and start-up support, targeted inward investment and the creation of supporting industry bodies. ITI Life Sciences is a new Scottish venture aimed at emerging global markets through technology development.

4.5.3 Creative Industry Cluster

Creative industries comprises film, TV and radio; multimedia; interactive leisure software (including packaged software); publishing; music; design; advertising; arts and cultural industries. SE commissioned the London School of Economics to report on the creative industries in Scotland to produce a measure of the scale, structure and employment in the creative industries in Scotland for the period 1981-1996 (Pratt 1999). It stated that, "the creative industries do seem to work with a dense connection of economic and social activities. As well as a proximity to end users of the product they tend to be urban activities, and imply a degree of spatial clustering; the key point seems to be the possibility of face-to-face interaction in the production; need to pay particular attention not only to traditional economic production networks, but also to social, institutional and learning networks that constitute the production system".

Following extensive consultation with industry, the Scottish Executive and SE launched the 'National Creative Industries Strategy' in August 2000, with an investment of £25m over 5 years. It identified the strengths and priority needs of the sector, and strategies were initiated in the wake of these findings. Scotland has particular strengths in 'Content Origination', (e.g. multimedia and games producers, film/ TV/ radio producers etc.). The fact that there are niche strengths in architecture, design, computer games, film, publishing & new media and that links have been forged between the software and the creative industries, all help to broaden horizons and develop an international perspective. Targets were set to grow the creative industries sector by 30% over the next 3 to 5 years, to raise exports to around 15% of the total Scottish export, and to create an additional 1500 to 2000 high quality jobs. Scotland has a greater concentration of employment in the creative industries than any UK region outside of London and the South-East of England. It supports over 100,000 jobs, and is estimated to be worth annual sales of £5 billion, and accounting for 4% of Scottish GDP (see Table 4.4). The creative industries as a whole are expected to continue to grow at an average of 10% p.a. over the period to 2007, but those parts which focus on the new media digital channels are forecast to grow at up to twice that rate, (up to 20% p.a.). The digital part of the creative industry includes: Communications Technology, Graphic Design, Animation, New Media, Computer Games & Electronic Entertainment. Pacific Quay site in Glasgow is being developed as a digital media centre. The games development industry alone employ around 500 in Scotland, with turnover estimated at £20 million, and is led by a small group of successful studios, such as VIS entertainment plc and Rockstar North.

Table 4.4 Creative Industries (2004)

	Employment	**Turnover**
Scotland	100,000+	£5.3bn+
UK	975,000+	£55bn+
Growth Projections	Non-digital industries 3-7% p.a.,	Digital industries 10-20% p.a.

In addition to businesses based in Scotland's central belt, a nucleus of games development firms has evolved around Dundee. ‘Interactive Tayside’, a partnership between public, private and academic sectors to promote Tayside’s digital media industry, was initiated. It is a local delivery mechanism that aims to build the digital media community in the area, with the objectives of encouraging higher levels of collaboration between companies and with academia, developing new commercial opportunities on a local, national and international scale and promoting high-quality skills and talents. There are two universities and three further education colleges in the field of digital media delivering research & development. There are about 350 digital media firms in Tayside, employing over 2300 and generating annual turnover in excess of £100 million. Academic strengths include the School of Computing at University of Abertay Dundee providing training and research in the interactive entertainment industry and networking with other similar institutions. A number of degree courses are delivered in co-operation with games developers and other firms from Scotland to Japan.

4.5.4 Scotland's Software Industry

Scotland's strengths in software include its research excellence in educational institutions and a pool of computer science graduates in Scottish universities, domestic demand drivers (e.g. Edinburgh financial institutions, Royal Bank of Scotland, Scottish Parliament/govt. etc.) and its employment potential. The industry is locally significant with potential for growth. There are number of institutional specialisation and software-specific policies in place e.g. Scotland IS, Software Academy, Graduates Into Software and the National Software Strategy. The software industry in Scotland has turnover of £2.335 billion with 30,000 employees. There are around 1200 software and e-business firms. It is mainly clustered around Scotland's central belt. World leaders like Hewlett-Packard, Cisco, Oracle, Sun, IBM and NCR have set up their base in Scotland. Moreover a number of large financial institutions such as the Bank of Bermuda and J. P. Morgan Chase have located their technical development teams in Scotland. Lucent, Agilent, NCR, Bank of Scotland etc. are some of the other major players.

4.5.4.1 Inclusion of Software as the Fifth Sector in the Research

The software industry in Scotland did not show up in the UK government's DTI cluster mapping exercise. Additionally, SE did not include it in their earlier cluster initiatives on technology clusters. The inclusion of the Software Sector in this research was undertaken considering a range of factors. It was concluded that not including the software sector would be ignoring (and underestimating) the sector's contribution to the Scottish economy and it would inevitably make this study of high technology in Scotland incomplete.

The SE sees the software sector not only as a distinctive and crucial industry in its own right, but also in its ability to enable other knowledge based industries to compete globally. "It is not only the health of a country's software industry per se that is important, but the degree of synergy that can be achieved with other high priority knowledge based industries within the national economic ecosystem", (Scottish Software Game Plan, SE 2003). It has synergistic benefit, i.e., knowledge based industries that are important to the Scottish economy benefit from direct support through a complementary indigenous and highly innovative software industry. In particular as an example, Life Sciences is an area where IT is a critical resource that provides advantages. It underpins new disciplines such as Bioinformatics, Proteomics, and Genomics. Another area of important synergy is between firms within the ICT industry as a whole such as: semiconductors, computers, software, data communications, and Internet.

Moreover, the inclusion of software sector also provides an explicit focus on a critical high technology service sector. Specifically, by taking into account that, ‘‘decades after services outdistanced manufacturing from an employment perspective, manufacturing has continued to dominate innovation studies’’ (Drejer 2004, p 551). The traditional view of service firms is as innovation laggards and that they are incapable of innovation and, at best, confine themselves to the adoption of technological innovations generated by manufacturing (Tether et al. 2001). However, small, knowledge-intensive business services (KIBS) are increasingly recognized as occupying a dynamic and central position in ‘‘new’’ knowledge-based economies, as creative innovators in their own right, rather than as mere adopters and users of new technologies (Freel 2006). Additionally, one of the striking features of the service sector is its tremendous diversity (Vermeulen & Wietze 2003). The highly heterogeneous nature of the service sector and recent statistics has shown sharply increasing innovation expenditures within a number of service sectors (Howells 2000). This recognition in turn, has stimulated significant recent research effort (Wong & He 2005), and is one of the motivations behind the inclusion of the software sector.

4.6 Conclusion

This chapter set out to present the policy framework, which led to the emergence of high technology in Scotland. A detailed description of the different stages in the history of evolution of electronics in Scotland was done in the light of the policy approaches at different times. An extensive review of the strengths and weakness of Scotland’s different hi-tech sectors was undertaken. A clear picture was also provided of the current hi-tech landscape in Scotland. This chapter also gives an insight into the selection of the high technology clusters for the purpose of this empirical study of hi-tech firms in Scotland.

Chapter 5 Instrumentation

5.1 Introduction

This chapter reports on the methodology adopted in the fieldwork activities undertaken, in this research on hi-tech firms in Scotland. The method and the design of the instrument, and the construction of various new measures to extract the information on the important variables, are a crucial aspect of this research and have shaped it in many ways. The data collection instrument used here was the structured questionnaires. This instrument was self-completed that was filled by the owner-managers of the hi-tech firms. Instrument design was a major part of the data collection process (Sekaran 1992; Oppenheim 1992).

The questionnaire design in this research is very distinctive, and involves a number of unique features. Firstly, whilst this is a cross-sectional study, data were gathered retrospectively for a five-year period for selected key measures, to capture firm dynamics. Thus the instrument incorporates features of both cross-section and time series data, to a certain extent. Secondly, it enabled the retrieving of very detailed, but easily comprehensible information on all stages of a very complex, interactive process in the hi-tech firms, which is the innovation process, (Hagedoorn & Cloodt 2003; Felder et al. 1996; Brouwer & Kleinknecht 1997; Kleinknecht 2000). Thirdly, it has attempted to quantify the firm's embeddeddness in the clusters, which hitherto has been regarded inherently qualitative in nature and hard to quantify. It also incorporated several novel measures to capture the firm's dynamic network intensity.

Section 5.3 provides a comprehensive explanation of the design. Two versions of the questionnaire were used in the fieldwork, a postal version and an electronic version and each had five sections. In addition, the questionnaire could be administered by telephone interview, on request. The multiple data collection technique greatly enhanced the response rate, as well as the completeness of the returns. The survey instrument was carefully piloted and improvements were made. Section 5.4 details the different phases in the implementation of the instrument (Reid 1993). Overall the instrument was successful in facilitating in-depth exploration of the characteristics of hi-tech firms. It illuminated cluster specific details and also the factors influencing innovation capability and performance. For illustration, a copy of a completed questionnaire is given in Appendix 3.

5.2 Instrumentation

The fact that personnel of hi-tech firms often have neither the time nor the capacity to answer detailed questionnaires on their internal innovation processes and external networks makes it extremely important to develop an instrument design which is both simple and non-confrontational. The Oslo Manual (OECD 1997, 1996), which sets out guidelines for the formulation and design of innovation surveys, and the questionnaire design inputs from the Centre for Business Research (CBR at the University of Cambridge, funded by the Economic and Social Research Council, ESRC), was used as a reference in the survey design for instrumentation. It deals with innovation at the firm level, and changes that involve a significant degree of novelty for the firm. It concentrates on new and significantly improved products (goods and services) and processes (Schmookler 1966). It recognizes that purely organizational innovation is widespread and may result in significant improvements in firm performance. It includes technical change as well as imitation, through questions on: products technologically new or significantly improved to the market, and products technologically new or significantly improved only to the firm. It is important that technical change should not be attributed only to production of goods. Older definitions may fail to capture a majority of service innovations unless redefined (Oslo Manual by OECD & Eurostat 1997).

Taking all these factors into account, innovation is defined here 'as new or improved products (goods and services), processes or organisational structures that are both new to the market and new to the firm'. Specific measures are used here to distinguish innovators from non-innovators. Many academic studies, which dichotomise firms as innovators and non-innovators, depending on observed outputs, are likely to be misleading (Freel 2005). In the current context, the likely consequence is an underestimate of the differences between innovators and genuinely non-innovative firms (i.e. those not attempting to innovate). To overcome this, firms are categorised as lying on a spectrum of low-tech to high-tech, (see Table 6.4, Chapter 6).

5.3 Questionnaire Design

There were 5 sections (A to E) in both the postal and electronic questionnaires as follows: *Section A- Performance, Section B- Resources,Section C- Collaboration & Co-operation, Section D- Embeddeddness, & Section E- Innovation,* (see Appendix 3).

The order of the different topics in the questionnaires was carefully designed to achieve the objective of extracting accurate and useful information. The questionnaire design according to these five sub-headings is influenced by the dense conceptual and theoretical considerations and the empirical evidence presented in chapter 3 and 4. The information collected aimed to gives a clear and distinctive picture of Scottish hi-technology. It enables one to identify the nature and type of firms like innovators versus non-innovators, and so on. In total, the survey instrument contained 22 numbered questions, roughly 4 questions in each section. The data from the survey on key indicators of innovation such as R&D expenditures, sales from new products has been supplemented by qualitative data like factors hampering innovation, objectives of innovation etc, thus incorporating both quantitative and qualitative indicators of innovation. This gives this research the advantage of using a range of important indicators on key topics. Thus qualitative evidence was useful for explaining quantitative results. The instrument design addressed the following:

- The instrumentation (postal and email questionnaires) does not involve face-to-face contact, so it was important to make it as short as possible and to include clearly formulated questions and instructions in order to achieve a satisfactory response rate.
- Instrumental design involved expressing the formal definitions in ways, which were appropriate and meaningful, to respondents in the industry concerned, notably in the service industries.
- The questionnaire was designed to be applicable to both manufacture & service firms.
- The questionnaire was designed for all five hi-tech sectors in Scotland. This common approach allowed a comparative view to be adopted in subsequent analysis.
- Sectoral representation was achieved by the sampling procedures.
- The use of a secondary industrial database as a source of empirical evidence has clear limitations as one has no control over the variables.. The questionnaire in this study was successful in collecting primary source empirical evidence using the desired variables (e.g. as dictated by the theory of innovation).
- The instrument design was cross-sectional, to which was added a time series element, incorporating questions for past five years on key variables.
- One feature of this instrument design is that it considers the three levels of innovativeness in firms, i.e., ‘high’, ‘low’ and ‘no innovation’ in order to assess their performance. The non-innovative firms are those with neither positive innovation input, nor positive innovation output during the period 1999-2003 and 2003-2007.
- The questionnaires was structured in five sections, designed to be simple, easy to comprehend, and to facilitate an easy flow during completion.

- There were around four questions in each section. Their design used different combination of closed-ended questions (e. g. binary, multiple choice, and ranking).

Each section of the questionnaire is discussed focussing on innovative ideas in the design.

Section A- Performance- The objective of the questionnaire's first section is to identify each firm's strength and competitiveness. The size and scale of firms and the growth of firms give an indication of micro-economic performance. There are five questions on performance in this section. It provides a number of important dependent and independent variables in the statistical and econometric analysis of hi-tech innovation, growth and export performance. This section captured important quantitative data on the following:

- *Q1. Employment, turnover and investment over five years*
- *Q2. Number of new or significantly improved products & services over five years*
- *Q3. Percentage of sales from new or improved products & services over five years*
- *Q4. Speed to Initial Public Offering*
- *Q5. Count of patents filed and patents granted over five years*

All questions except Q4 gathered data from period 1999-2003. Q2 also gathered data for 2003-2007. The first question gathered data on employment, turnover and investments over the previous five years. The advantage of these retrospective measures over others is that the data on employment and turnover were easier to recall and were not subject to differences in accounting conventions like depreciation of assets values etc. The turnover and employment variables were subsequently used in testing the Gibrat's Law of Proportionate Effect in chapter 7, (Mansfield 1962; Singh & Whittington 1975; Dunne & Hughes 1994; Reid 2001). They were also used to as explanatory size variables in statistical models of the non-linear size-innovation relation, using the functional form of a cubic equation (Grabowski 1968; Bound et al. 1984; Pavitt et al. 1987; Acs & Audretsch 1991). The latter issues are explored in chapter 7 on hi-tech performance.

The literature suggests that consistent innovative performance is the most important factor for the survival and development of a hi-tech firm characterised by technological uncertainty, complexity, rapid change and intense global competition (Lefebvre & Lefebvre 2002; Klomp & van Leeuwen 2001; Lööf & Heshmati 2006). The innovation output (such as new products and patents) is an indicator of a firm's innovative performance (Crepon et al. 1998). Here, the number of new (or significantly improved) products (or services) introduced in the last five years is used as an indicator of the innovativeness of firms. One drawback of this indicator is that it excludes purely development firms, i.e. firms having products and services still in the development stage, and entirely new firms. Though such firms may not have launched any products or services, this does not mean that they are less innovative. To take this into account, the time lag involved between the innovation input and the resulting output, and the firm's projection of innovation output (here, the number of new products & services in the next five years) are also included. At this place, firms also indicate the effects that factors such as formal alliances, R&D expenditure, informal network, economic performance etc., have on future innovative performance of the firm. Innovation performance is an important dependent variable in the econometric estimation of a non-linear cubic model of the innovation-size relationship. It is also, an important explanatory variable in econometric model of exports. The specific question design used to address the present and future innovative performance of firms, was as follows:

Q2a. *How many new or significantly improved products (goods or services) have you introduced in the last five years?* ______

Q2b. *How many do you intend to introduce in the next five years?* ______

This format of question was also used to gather data on both patents granted and the patents filed in the last five years (Q5 above). A common approach to questionnaire design in this research is to use percentage of sales from new or improved products rather than indicators based on counting. The latter has the drawback that all innovations are valued equally be they patents or number of new products (see section 2.5, chapter 2). The value added from innovation (OECD & Eurostat 1997; Crepon et al. 1998), is also used as measure of innovative performance here. This is an important endogenous variable in the econometric simultaneous model of performance, innovation and networks (refer chapter 10). Speed to Initial Public Offering was also gathered as a performance measure.

Section B- Resources- The second section aims to gather information on firm specific resources. The six questions in this section were as follows:

- *Q1. Number of full time staff in four occupational groups*
- *Q2. Total proportion of workforce with university degrees (managerial & research)*
- *Q3. Training expenditure as a percentage of total labour costs.*
- *Q4. In-house R&D department*
- *Q5. Annual R&D expenditure*
- *Q6. Lead-time required for product development*

The objective here was to gather information on the firm-specific resources of innovation-intensive hi-tech firms. This is of importance because technical knowledge is the main strategic resource to be developed or acquired (Hage & Alter 1997) by the hi-tech firm. As seen in chapter 3 (section 3.3.1), in-house R&D activities are often perceived as the most effective way of accomplishing this (Meeus & Oerlemans 2000; Oerlemans et al. 1998; Baumol 1993; Rothwell & Dodgson 1991; Contractor 1983). R&D activities are important, not only for developing the firm's product and process innovations but also for monitoring competitors and absorbing the latest technological trends on the market (Lenox & King 2004; Harabi 1997; Cohen & Levinthal 1989, 1990). Moreover, internal resources often act as complements to, or indeed appears to negate the need for, external resources (Freel 2003). Firms require '. . . substantial in-house capacity in order to recognize, evaluate, negotiate, and finally adapt the technology potentially available from others' (Dosi 1988, p. 1132); see also Cohen & Levinthal 1989, 1990). This section of the questionnaire thus facilitates an in-depth examination of the firm's in-house resources like human capital, R&D investment, and the role of R&D department in facilitating long-term innovation effort. These question design facilitated the computation of many important explanatory variables in the econometric analysis of chapters 7, 8, 9 and 10, and also the summary statistic analysis of chapter 6.

Section C- Collaboration and Co-operation- This third section of the questionnaire specifically focused on the dynamics of the networking process to which hi-tech firms are subjected. In the literature, networks are seen to have a significant positive impact on firm performance (Ritter & Gemünden 2003; Criscuolo & Haskell 2003; Janz et al. 2004; Lööf & Heshmati 2002; Vanhaverbeke et al. 2004; Cincera et al. 2005). This section of the questionnaire provides the basis for the analysis of the extent of hi-tech networks and embeddeddness, which is performed in chapter 9 and 10. In doing so, it aims to contribute to the growing literature on the link between innovation and network in firms (Chesbrough 2003a; Stuart 2000; Hagedoorn 2002; Baum et al. 2000; Rominj & Albaldejo 2002; Porter & Ketels 2003), and to the regional innovation networks literature. It has policy implications too, especially since Scotland's industrial policy is built around an extensive cluster policy (SE 1998), with an emphasis within the clusters to use networks, both nationally and internationally (see chapter 1, section 1.5 & chapter 4, section 4.4).

To my knowledge this is the first work of its kind, which develops insights into the complex dynamic networking behaviour of hi-tech firms in Scotland. In particular, the questionnaire design of this thesis was able to identify the nature of the Scottish hi-tech firm's networking across seven different type of collaborators: suppliers, customers, competitors, research organisations such as universities, government organisations, trade and professional associations and finally financing venture organisations. This was accomplished by using three questions:

- *Q1. Location of the 7 different collaborative partners*
- *Q2. Frequency of contact*
- *Q3. Total number and purpose of alliances with external agents*

These questions contributed to discovering the extent of networks, and laying the basis for the analyses of different vertical and horizontal linkages (see chapter 9). The detailed data obtained on the spatial network patterns facilitated the testing of the hypotheses:

(a) Does proximity increases alliance intensity?

(b) Do SME's have greater dependence on networks than large firms?.

The first question of this section of the questionnaire extracted information on the location of firm's collaborators across five locations (Local, Scotland, UK, Europe and Outside Europe) for each network type, as indicated here:

Q1. Firms use collaborators to develop new or improved products, processes or organisational structures. Where are your collaborators located? (Please tick)

Collaborators \ Locations:	*Local*	*Scotland*	*UK*	*Europe*	*World*
Suppliers	____	____	____	____	____
Customers	____	____	____	____	____
Competitors	____	____	____	____	____
University / Research	____	____	____	____	____
Government bodies	____	____	____	____	____
Professional / Trade	____	____	____	____	____
Financing	____	____	____	____	____

The second question focussed on the frequency of contact with each of the 7 collaborators using a 6-point Likert scale, where 0 = no contact, and 5 = very frequent contact. The third question captured the number of alliances with each of the 7 collaborators and the purpose of alliance. It thus facilitates the construction of a novel measure on the alliance intensity of hi-tech firms, which enabled comparisons to be made across different networks and also across different regions, (see chapter 9). These variables were also important explanatory variables for representing external networks in the simultaneous equations model of performance, innovation and networks in chapter 10, and in the tobit model (with sample selection), on the determinants of export performance, in chapter 8.

Section D- Embeddeddness- The fourth section of the questionnaire was concerned with how solidly Scottish hi-tech firms are embedded in the economy. Theoretical concepts of 'Industrial Districts' (Brusco 1998; Marshall 1920), 'Regional Innovation Systems' (Cooke 2001b, 2002a), and 'Innovative Milieu' (Aydolt 1985; Cappello 1999; Camagni 1996), suggest that embeddedness in networks, and interdependence among agglomeration of firms stimulates innovation (see chapter 1, section 1.4). Drawing upon this literature, especially that on the Innovative Milieu, this section on embeddeddness aims to capture detailed information on the hi-tech firm's formal and informal links. It explains how spillover effects influence embeddeddness in a region or milieu, by examining factors such as a firm's local recruitment links, and informal links. Further it explores spillover through the movement of employees between firms located in Scotland, the background of firm's founder, and the proportion of the firm's purchases and sales across five locations. Briefly these four questions were on:

- *Q1. Firm recruitment*
- *Q2. Informal links*
- *Q3. Background of entreprenure*
- *Q4. Proportion of the firm's purchases and sales to the five locations*

This section of the questionnaire facilitated the gathering of new information on distribution of sales and purchases in different regions. It thus provided the basis for an evaluation of the embeddeddness of (as opposed to the versus internationalisation process) hi-tech firms (see chapter 8 on hi-tech internationalisation and chapter 9 on embeddeddness).

Section E- Innovation- This last section of the questionnaire aims to gather data on the importance of innovation, according to the hi-tech firm's perception. There are four questions in this section. The first one is on the annual innovation expenditures spent by the firm. Innovation expenditure is a relevant innovation input measure, especially for service firms, and indeed small firms in general, as it includes other expenditures on innovation, especially for market near activities other than R&D (Gottschalk & Janz 2001).

Q1. How much do you currently spend per year directly on innovation?
(e.g. R&D + purchase of capital equipment + patents + licences + training)
Innovation expenditure £ ___________000s

The rest three questions are important qualitative measures on the importance of innovation on a Likert scale of 1-5. It deals with the objectives of innovation, sources of innovation and factors hampering innovation in firms. Question (2) is given below to illustrate.

Q2. How important are these sources of information in stimulating innovation in your firm?(Mark on scale of 1 to 5, where 1=unimportant, 5=very important and mark 0 if irrelevant)

Internal	*(e.g. R&D staff, marketing staff)*	____
Market	*(e.g. customer, supplier, competitor)*	____
Educational & Public	*(e.g. govt. agencies, universities)*	____

5.4 Implementation of the Survey Instruments

The implementation of the data collection process was an important aspect similar to the structure of the questionnaire in order to attain high response rate and for the quality of the detailed and accurate data. It can be assumed that the database was very reliable as the data were cross-checked through a telephone. Implementation of the questionnaires was carried out in the period, Aug 2003 to February 2004 and was done in four phases: Pilot phase where pilot survey on a small sub-sample was done; Implementation of postal questionnaires and electronic version of the questionnaire was done sector-wise in the five sectors of Optoelectronics, Microelectronics, Digital Media, Life Sciences and Software; Call-back phase where follow-up calls were used to pursue successful returns of completed questionnaires; Coding of variables were done next and in the last phase the data from the return questionnaires were checked and database was created. 836 questionnaires were posted to all the firms in the sample (Optoelectronics 80, Microelectronics 187, Life Sciences 150, Creative Digital Media 187 and Software 230). Prior to this, a database of the addresses of all the recipient firms was developed and the Standard Industry Classification (SIC) noted for each of the 836 firms in the sample, (see Chapter 6, section 6.2 and 6.3 for details).

Phase 1: Pilot Survey (Aug 2003)- Stratified random sampling was used to select the sample size for piloting. The initial pilot sample size was 30 according to the size of each of the five strata. Opto-electronics was over-sampled by 3 and thus the pilot sample was raised to 33. The method of stratified sampling to achieve the pilot sample size is given in the Table 5.1. There were 16 responses to the pilot survey, with a response rate of 48%. Even then a number of points were noted in the light of the pilot survey and few solutions and recommendations were incorporated for the full survey. Identification code was included on the address label on the back of the questionnaire. It was a five-digit code in the format ‘XYYY’ where the first digit ‘X’ is the sector code and runs from 1 to 5 for each sector. ‘Y’ stands for number from 1 to 836. A covering letter (see Appendix 1), self addressed envelope (sae) and CV were enclosed along with the questionnaire for all the firms. Return dates of two weeks for postal return and five days for e-mail return were also specified in the covering letter to ensure prompt feedback.

Table 5.1 Pilot Sample

Sector	**Full Sample**	**Stratified Sample**	**Pilot Sample**
Optoelectronics	80	$(80 \div 836) * 30 = 3$	3+3 = 6
Microelectronics	187	$(187 \div 836) * 30 = 7$	7
Digital Media	189	$(189 \div 836) * 30 = 7$	7
Life Science	150	$(150 \div 836) * 30 = 5$	5
Software	230	$(230 \div 836) * 30 = 8$	8
Total	**836**	**30**	**33**

Phase 2: **Postal** Questionnaires Targeted to the Sample Firms, by Sector- As mentioned earlier, the instrument was posted to the firms sector by sector. The whole process was implemented in the period from Oct 2003 to Jan 2004. The postal questionnaires were posted sector-wise in the following order: Optoelectronics 80, Microelectronics 187, Life science 150, Digital media 189, and Software 230. The response rate was 19% for the whole sample. The response rate sector-wise is given in the table 5.2.

Table 5.2 Questionnaire Response Sector-wise

Sector	**Sample Size**	**Questionnaire Completed**	**Response Rate**
Optoelectronics	80	28	35%
Microelectronics	187	32	17%
Digital Media	189	32	17%
Life science	150	33	22%
Software	230	33	14%

Phase 3: Call-Back & Follow-up -Role-play was done as a preparation prior to the follow-up. Follow-up call was done within ten days of the dispatch of each set of postal

questionnaires. The option of administering the questionnaire over the phone by interview was offered. An electronic version of the postal questionnaire was also offered according to their preference. A set of formal guideline (see Appendix 2) was used to assist in approaching the call back phase in a consistent manner. This method was followed for all the sectors. The follow-up, by means of phone calls, was very effective in increasing the number of completed questionnaires returns.

Phase 4: Coding of the Variables -This phase followed, after the despatch of postal questionnaires were completed. Coding involved up to 131 variables. A glossary of definitions of all the variables was created and the type of each variable, e.g., numeric/string, real, count, date, binary or categorical were also stated. A copy of this is given in Appendix 4.

Phase 5: The Data -Target on the sample size was achieved (158), which allowed a response rate of 19%. SPSS Version 11.5 was used for mounting the data in the ascending order of identification codes. Data cleaning were done. The return questionnaires were checked for missing important information and other mistakes and the firms were contacted to clarify wherever required. Summary statistics were done on the key variables using the data, (see section 6.4 for the summary statistics).

5.5 Conclusion

This chapter set forth to give an extensive account of the instrumentation methods used in this research. It is evident that the method of structured questionnaires has significantly contributed to the data collection process, as well as to this research as a whole. Many novel features were incorporated in the design and construction of the questionnaire so as to achieve the highest quality possible for this research. Relevant literature and past empirical research have greatly influenced the instrument design. The structured questionnaire had five sections: Performance, Resources, Collaborations, Embeddeddness and Innovation. Both the piloting and implementation of the instrument have been highly satisfactory. It can be concluded that the instrument devised here achieved the goal of facilitating the creation of an accurate and useful database on hi-tech firms in Scotland, and thus facilitated this research on hi-tech performance, innovation and networks.

Chapter 6 Sampling & Summary Results

6.1 Introduction

The first part of this chapter details the sampling procedure used in constructing the sample frame, by illustrating the different stages involved. In the second part, the characteristic features of the firms in the high technology sample are examined. A multi-stage sampling technique, involving cluster, quota and stratified sampling was used to construct the final sampling frame. The method of cluster sampling was conducive to focussing the study on five high technology sectors, or clusters, of life sciences, software, optoelectronics, microelectronics and digital media technology, in Scotland. Stratified quota sampling enabled the creation of a sample frame that is representative of these five hi-tech sectors.

Section 6.2 outlines the process of extracting the sample frame of 836 firms from the population of Scottish hi-tech firms that was described in chapter 4, (refer section 4.5, 'The current high technology structure in Scotland). Five databases relating to the five hi-tech sectors were constructed initially, which constitutes the 'hi-tech population'. This was used in identifying the firms for inclusion in the sample frame. In the case of SIC-based sectors, the technology-based firms were identified using the definition of high technology of Butchart, (Butchart 1987, 'A New UK Definition of the High Technology Industries'). For non-SIC-based sectors, various sources and information such as the methods used by the DTI (Department of Trade and Industry) enabled the extraction of technology-based firms. Section 6.3 and 6.4 explores the composition and representativeness of the sample frame. The statistical make-up and composition of the sample, and how it compares with the 'Scotland population' (firms in all sectors in Scotland), are elaborated in Section 6.4, by analysing key summary statistics. It thus highlights the characteristic features of these hi-tech firms. This section also investigates the different characteristics of large, medium, small and micro sized firms, and specifically discusses the implications of these differences for innovation in firms. Section 6.5 concludes this chapter.

6.2 Sampling Techniques and Sample Design

The sample frame for this research on Scottish high technology was developed by the method of multi-stage sampling technique and involved four stages. In assembling this data set, an attempt was made to confine the sample to the hi-tech sectors, since the focus of this research was on hi-tech performance, innovation and networks. The first stage thus comprised cluster sampling, which was conducive to streamlining the research focus on to the key hi-tech sectors from within the hi-tech population in Scotland as a whole. The selection of the optoelectronics, microelectronics, life sciences, digital media and software was done in the light of Scottish Enterprise’s cluster policy initiatives on key technology clusters, (refer chapter 4, section 4.4; chapter 1, section 1.5 for a detailed account). This method was quite efficient considering the cost of search and also the fact that these five clusters were in many ways the exemplars of Scottish high technology.

Next, five databases of the complete list of firms in each of these five sectors were constructed. This represented the five strata, and the proportions of firms in each of these five strata were noted. Thus the variable ’sector’ was used as the stratification factor. In the next stage, the firms in each of the five databases were further stratified to a number of different sub-strata depending on each sector composition. This is illustrated in section 6.3. This was made possible by contacting various organisations such as Biotech Scotland, Scottish Optoelectronics Association (SOA), Scottish Microelectronics, Scotland IS for software, Interactive Tayside for digital media etc. A number of other websites also provided the details.

In the final step technology-based firms alone were extracted from the databases. Firms in SIC-based sectors were isolated using the SIC codes that comes under hi-tech definition by R. L. Butchart 1987 and C. Thompson 1987. The SIC codes are presented in Appendix 5. For non-SIC based sectors, other sources such as the Department of Trade and Industry (DTI 2000, 2001) were used. In the end, 836 technology-based firms constituted the sample frame for this empirical study.

6.2.1 Sampling Problems in constructing the Sample Frame

A number of problems were addressed in the process of identification of firms. In chapter 1, section 1.3, the cluster definition, description and their components were described. It is seen that clusters are essentially ‘a concentration of competing, collaborating and interdependent companies and institutions which are connected by a system of market and non-market links’, (DTI 1998). Thus there exist a number of varied components like academic institutions, research organisations, trade bodies etc. In this research, the focus is only on firms or businesses in these clusters or sectors. Hence, the first step involved cleaning the database of all other components by deleting other components and extracting only the relevant firms. Moreover, all the firms that were extracted from the five hi-tech sectors were not necessarily technology-based firms, as the firms that were left included both technology-based firms as well as non-technology based firms, such as recruitment consultancies, marketing firms etc. Hence some steps had to be taken to isolate the technology-based ones. The second problem in sampling thus involved isolating technology-based firms from the rest. For their research, Butchart's new definition of UK high technology (Butchart 1987) was based on UK SIC codes and Thompson's definition of high technology was based on US SIC codes (Thompson 1987). In both cases the 4-digit level were used (see Appendix 5).

But even at the 5-digit level, SIC categories were not able to capture the activities of firms in certain hi-tech sectors. The selection was not much of a problem for optoelectronics, microelectronics and digital media, as most of the firms satisfy these criteria. But the selection for life sciences and software was more time consuming, as only a fraction of the firms in these two sectors were in fact technology-based. Various sources and information were referred to, and had to be included, such as the methods used by DTI for the identification in the non–SIC-based clusters. The DTI, in their cluster mapping used local information and other sources (Dun & Bradstreet) to identify the non-SIC-based ones, such as optoelectronics, biotechnology etc (DTI 2001 vol. 3), (see chapter 4, section 4.3).

Moreover, in the case of software, the industry is a complex phenomenon that encompasses a very broad range of industrial classifications. Software sector activity itself is subsumed under a wide range of industries. Currently there is no single specific definition or formal industrial classification of the 'software industry' (McNicoll & Kelly 2003). Given the complexities surrounding any definition of software sector activity, too narrow an identification runs the risk of considerable areas of 'software sector' activity being omitted. Conversely, too broad an identification can end up making any definition derived meaningless, since it will in effect comprise the whole economy as software is used, adapted or developed in almost every industry in one way or another. In this research the report to Scottish Enterprise (SE), 'Economic Frameworks for policy relevant analysis of the Software Sector in Scotland' (McNicoll & Kelly 2003) has been suggestive for identifying the software firms.

6.3 Selection & Design of the Final Sample

The selection, composition and size of the various strata in the 5 sectors are presented.

Software- The Scotland IS, the Lanarkshire Software and the Rampant Scotland Directory were the three different sources of database used in the case of software firms. As mentioned above, the software firms were identified by referring to the report to SE, by McNicoll & U. Kelly (2003). The database had a total of 318 firms from these three sources. Only 230 firms were included in the sample. The following SIC codes enabled the extraction of these firms.

7371 (US) Computer Programming Services

7372 (US) Pre-packaged Software

7902 Telecommunications

8394 Computing Services

The number of firms in the software population (left column) and those included in the sample (right column) to represent the software sector of Scotland is as follows:

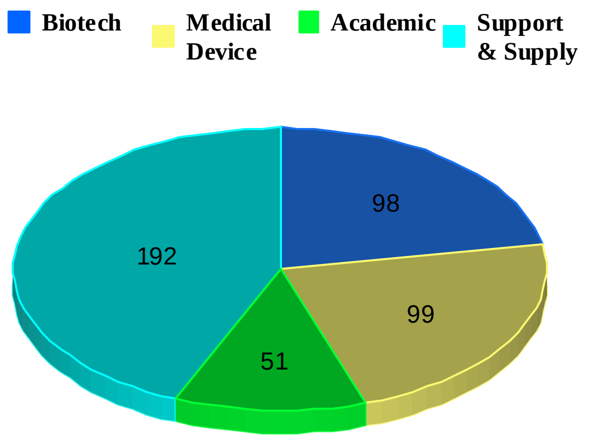
	Software-Population	**Sample**
Software IS	186	186
Lanarkshire software firms	52	19
Rampant Scotland directory	80	25
Total	318	230

Life Science- The database for life science sector in Scotland was gathered from the Biotech Scotland, the organisation that represented life science in Scotland. The life science sector was composed of a total of 440 organisations in the four categories, (see Figure 6.1). It comprised firms involved in biotechnology, medical devices, various support and supply activities that do not necessarily involve technology firms, and research and academic organisations that contribute to the sector in terms of break-through research, spin-offs and quality skilled labour. In order to capture the activities of firms in the Life Science sector, the procedure used by the DTI is followed here, and the following terms were recognised: *'Biological products & process', 'Biotech products & process',' Diagnostic products & process', 'Genetic products & process', 'Molecular products & process', 'Therapeutic products & process', 'Peptide products & process', 'Protein products & process', 'Reagent products & process',' Serum products & process' and 'Biotechnology research'.*

Moreover, the SIC codes from the definition of hi-tech firms from both the UK (Butchart) and the US (Thompson) were used to identify the firms. The codes are:

SIC codes by Butchart		***SIC codes by Thompson***	
2570	*Pharmaceutical Products*	*2831*	*Biological Products*
3720	*Medical & Surgical Equipment*	*2833*	*Medicinal & Botanicals*
	& Orthopaedic Appliances	*2834*	*Pharmaceuticals Preparations*

Figure 6.1 Distribution of Firms in Life Science Sector



It was found that only a fraction of the firms in the sector were technology-based. 150 firms were included in sample to represent the life science sector. The distribution is as follows:

Biotechnology	85
Medical Devices	44
Support & Services	21
Total	150

Microelectronics- The Scottish Microelectronics database was referred to, in order to create the database for the microelectronics sector. Out of the 203 firms that comprised the microelectronics population database, 187 firms were selected to represent the microelectronics firms in the sample, and the following SIC codes were used to identify:

3301 Office Machinery Manufactures

3302 Computer Hardware

3441 Telecommunications Equipment

3710 Measuring, Checking & precision Instrument

The distribution of such firms in the microelectronics population and the sample are:

	Micro-Population	**Sample**
Silicon manufacturers	7	7
Design	75	75
Product Development	26	26
Embedded Software	79	79
Applied & Exploratory Research	16	-
Total	203	187

Optoelectronics- In the case of optoelectronics, the Scottish Optoelectronics Association (SOA) database was used to prepare the list of firms. The firms that were selected featured the following, in either the name of the company, or (more importantly) the description of what the company does: *'Chromatography',' Laser',' Optronics', 'Optical', 'Photonic', 'Spectroscopy' and 'X-ray'*. In addition, the following SIC codes also enabled the selection of optoelectronics firms:

4813 Telephone communications except radiotelephone

4812 Radiotelephone communications

3827 Optical instruments & lenses

3695 Magnetic & optical recording media

3679 Electronic components

3674 Semiconductor & related devices

3652 Disc laser

The final sample thus included a total of 80 firms representing the optoelectronics sector.

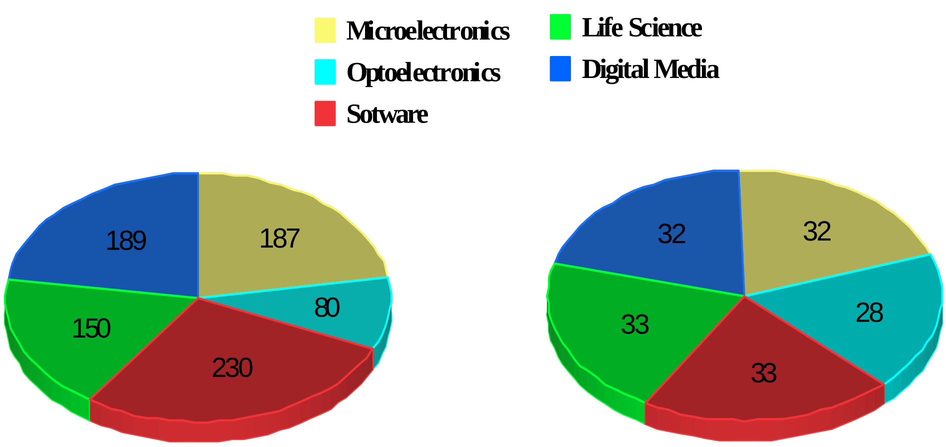
	Opto- Population	**Sample**
Optoelectronics	60	60
Services	13	11
R&D	9	9
Academic	8	-
Total	90	80

Digital Media Technology- The database for the digital media firms were created by contacting the 'Interactive Tayside for Digital Media' and their list of firms were used. A total of 189 firms were selected in order to represent the digital media firms in the sample from a population of more than 200 firms in this sector. The creative digital media technology being a non-SIC-based sector, the firms were extracted by selecting those firms whose activities included one of these:

'Communications Technology', 'Graphic Design', 'New Media', 'Computer Games & Electronic Entertainment'.

The sample frame of 836 is the result of adding the number of firms selected from different strata in each of the five sectors. The survey instrument was targeted at all 836 firms in the sample and 158 response were received. The sample and hi-tech population distribution of firms in the five sectors are compared in Figure 6.2.

Figure 6.2 Hi-tech Population & Sample- Sector-wise Distribution



Tests comparing the distribution of technology-based firms in the five sectors of the sample with that of the hi-tech population were performed. The χ^2 test has confirmed that this sample is representative of the hi-tech population, (χ^2 test statistic 9.42 does not exceed the critical value 9.49, v=4, 5% sig.).

6.4 Composition and Description of the Sample

The statistical make-up of the sample is examined here by reference to the key summary statistics, and attempt is made to undertake appropriate comparisons with the Scotland population wherever possible. The comparison is with the figures for all sectors in Scotland, published by the Scottish Executive National Statistics Publication (Scottish Economic Statistics 2005, 2004), and not with hi-tech sector alone, as the full figures for the hi-tech sector are not available. The data for the sample is for the year 2003 hence the comparison is with the 2003 Scotland population figures. The basic composition of the sample with respect to sector, size, age, exports, and high-tech versus low-tech etc. are discussed. In this process the main characteristic features of the firms in the hi-tech sector are highlighted. Sections 6.4.1 to 6.4.9 compare the hi-tech sample with the Scotland population with respect to sector composition, start-ups, employment and exports. Comparisons on R&D intensity, R&D across size, age and sectors, and finally patent applications and patents per million R&D expenditures are also undertaken.

6.4.1 Sectoral Composition of the Hi-Tech Sample

It is argued that the sample constitutes a good representation of firms in the five hi-tech sectors of Scotland. χ^2 tests was performed to see whether all the sectors were equally represented in the sample, as given in Table 6.1.

Table 6.1 Sector-wise Distribution of Firms Comparison

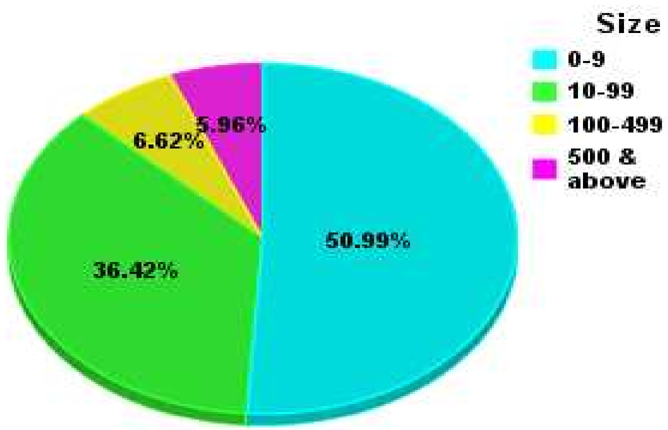
Sectors	Sample (O)	Hi-tech Population (E)	(O – E)	$(O – E)^2$	$(O – E)^2 / E$
Optoelectronics	17.72	20	2.28	5.198	0.2599
Microelectronics	20.25	20	0.25	.062	0.0031
Digital Media	20.25	20	0.25	.062	0.0031
Life Science	20.89	20	0.89	0.792	0.0396
Software	20.89	20	0.89	0.792	0.0396
Total	100	100			0.3453

The test statistic of 0.345 is less than the critical value of 9.49 (v = 4, 5% significance). The null hypothesis, that there is no difference in the proportion of firms in the five sectors is therefore accepted.

6.4.2 Size Distribution

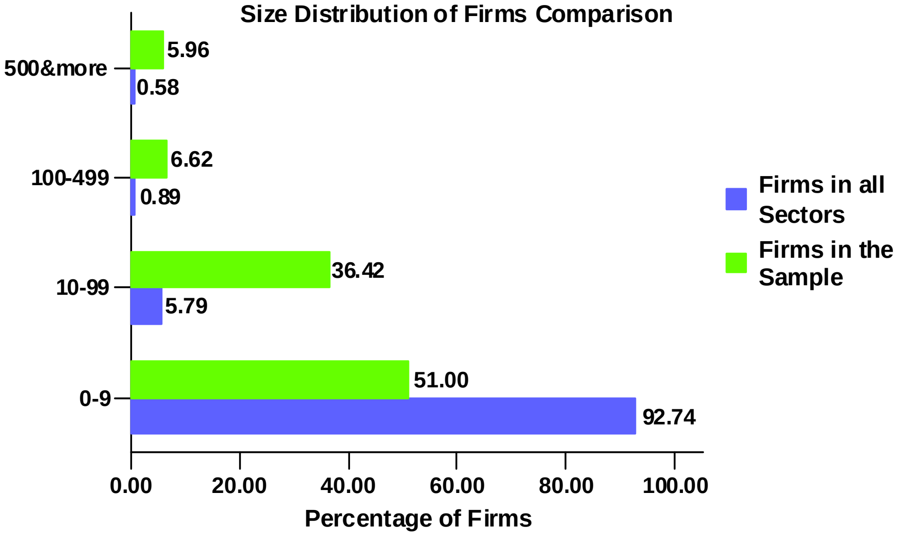
Size can be calibrated by many different measures, such as turnover, assets, output and employment. Turnover and employment in 2003 are specifically examined here. The turnover varied from 0 to £600 million with the average, median and mode being £15.48 million, £0.35 million and £0.3 million, respectively. 5.2% of the firms in the sample did not have any turnover in 2003. More than 43.45% (37.53) of the turnover in 2003, on an average was raised from new product sales (standard deviation is in parentheses). In this research the classification of firms by employment size is based on the definition by the European Community (Eurostat 1994). Figure 6.3 presents the sample size distribution according to: *Micro (0 to 9); Small (10 to 99); Medium (100 to 499); Large (500 and above).*

Figure 6.3 Employment Size Distribution of Firms



The predominant firm type in this sample is the micro-firm (51%). The average firm size is somewhat raised due to the existence of few large firms in the sample. The number of employees in the sample varied from 1 to 5000 employees in 2003 with the average and median being 118 and 9 respectively. 94% of the firms were SMEs, having less than 500 employees. This is comparable to that of the Scotland population where the SMEs constitute 99%. Figure 6.4 presents the comparison, (source Scottish Economic Statistics 2004; Scottish Executive ONS (IDBR)). In 2003 there were 262,545 firms or businesses in Scotland. Comparing the sample with that of the Scotland population, it is evident that unlike the Scotland population where the firms are predominantly micro firms (92%), in the sample it is only 51%, i.e., the sample has a higher proportion of small, medium and large firms. The χ^2 test statistic of 267.61 exceeds the critical value of 7.815 confirming that the size-distribution of firm in the sample varies from that of the Scotland population.

Figure 6.4



Moreover within the sample, the characteristics of firms varied across size group. Table 6.2 presents a comparison of age, turnover, productivity etc., across the four size class. The age, turnover and labour productivity were higher for larger firms. A test of the null hypothesis of the equality of mean across firm type was rejected using ANOVA (see Table 6.2, F stat=36.77, v=3, significant at 1% for turnover). The Post Hoc tests revealed that averages were higher for large firms compared to micro, small and medium firms.

Table 6.2 ANOVA Sample Firm Characteristics -Comparison of Mean across Size

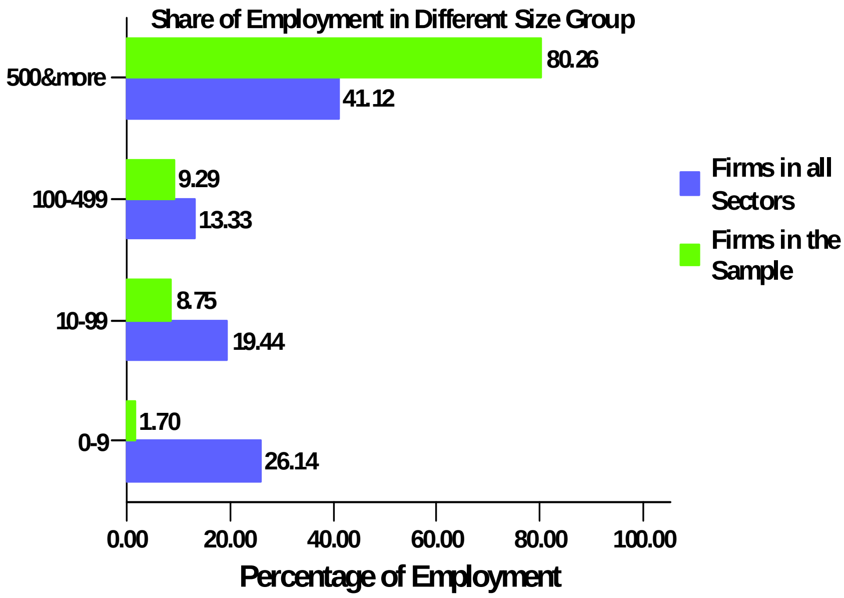
Variable	Type of Firm				F Test	Sig.
	Micro	Small	Medium	Large		
Employment	4	28	165	1591	62.983	.000
Turnover in million	0.31	2	14.88	203.13	36.777	.000
Age	3.87	4.42	4.6	5	4.036	.009
Labour Productivity	60.63	61.46	85.77	150.93	2.709	.048

6.4.3 Share of Employment across Firm Size

It has revealed that the largest employers in Scotland were the large firms. This is true for both for the Scotland population, as well as for the hi-tech sample. But the notable difference is that, the share of total employment across different sizes is significantly different for the sample compared to that of the Scottish population, (χ^2 test 5% significance, v = 3). In the case of the Scottish population, large firms employed 41.12%, whereas in the case of the sample, large firms employed almost double i.e. 80.26%, (see

Figure 6.5). A χ^2 test to compare the ratio of employment share across size-classes, shows that it is different between population and sample (significant at 5%, v = 3). Thus for the sample, even though the large firms constituted just 6% of the sample their contribution to employment was more than 80%. The disturbing fact is that, even though the SMEs constituted 94% of the sample, their share of employment was very low, at less than 20%. This compares to the Scotland population, for which the SME share of employment was about 59%. It can be concluded that the major employers in the hi-tech sector in Scotland are a handful of very large firms. The hi-tech SMEs have not succeeded in creating employment in the hi-tech sector, even though they constitute a vast proportion.

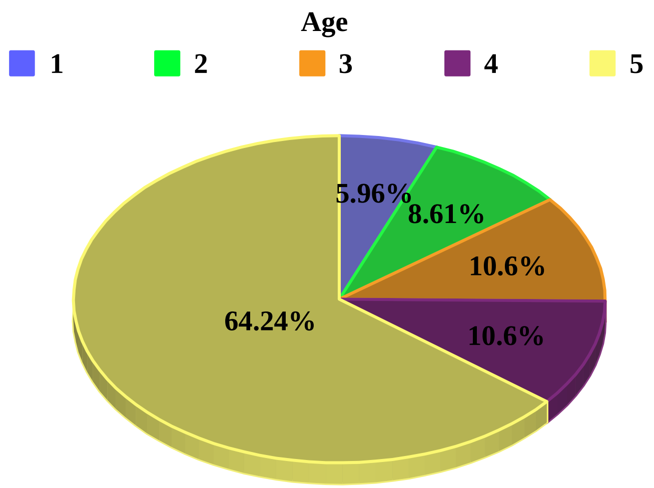
Figure 6.5



6.4.4 Start-ups and Age Distribution

Just 6% of the firms in the sample were start-up firms that were 1 year or less. In this sample nearly two-thirds of the firms were at least five years old, (see Figure 6.6). In 2003 the numbers of start-ups were 52 in Scotland, 753 in UK and for the sample it was 9. The 2004 statistics show that 65% of the firms were started in the three years (2001 to 2004) for the Scotland population. This is comparable to 22.15% of firms that were started in the three-year period (2000 to 2003) for hi-tech firms in the sample. There are few micro & small development firms which do not have any products (7%).

Figure 6.6 Age-wise Distribution of Firms



The size-age cross-tabulation is presented in Table 6.3. It reveals that the sample mostly constitutes micro and small firms, in the age group of around 5 years. Large firms in the sample were all at least 5 years from inception. Moreover, none of the new firms were of medium and large size. This indicates that hi-tech firms that are large tend to be mature firms and the new young firms are more likely to be of micro size. There is a significant, weak positive correlation between size and age (Pearson's R = .268, Sig. 1%).

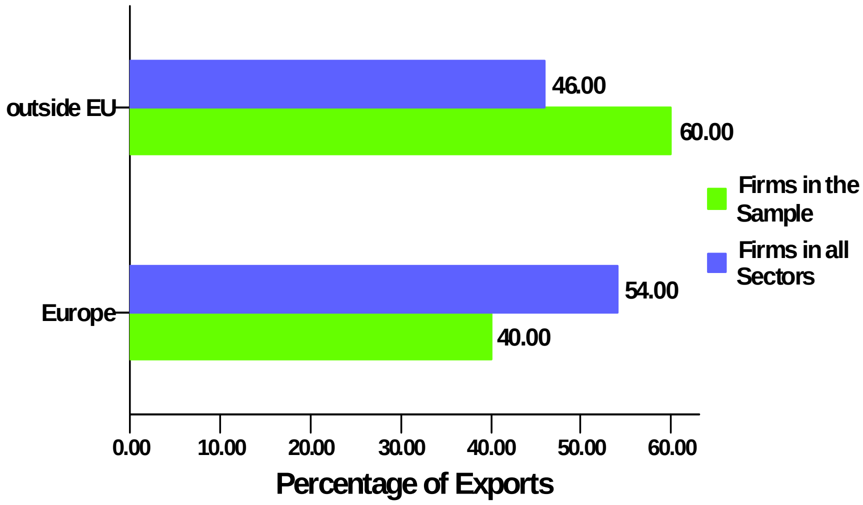
Table 6.3 Size of Firms by Age

Age	Micro	Small	Medium	Large	Total
1	5.3%	.7%	-	-	6.0%
2	7.3%	1.3%	-	-	8.6%
3	5.3%	4.6%	.7%	-	10.6%
4	4.0%	5.3%	1.3%	-	10.6%
At least 5 years	29.1%	24.5%	4.6%	6.0%	64.2%
Total	51.0%	36.4%	6.6%	6.0%	100

6.4.5 Export Performance

The value of exports in 2003 was £18.76 billion for the Scotland population. The share of exports by the electronic industry was 24%. Scottish firms exported £10.1 billion (54%) to Europe and £8.6bn (46%) to the rest of the world. In the case of this sample, exports to Europe were about 40% and exports to rest of the world were 60%, much higher than in the Scotland population (46%), (see Figure 6.7).

Figure 6.7 Export Extent of Firms Comparison



The χ^2 test confirms that the export extent is indeed different, as the test statistic of 8.52 is greater than the critical value 3.84 (v = 1, 5% sig.). Exports account for about three quarters (72.81%) of the firm's total sales. Moreover, over 36% of the firms had greater export sales compared to sales in domestic markets, and about 5.15% of the firms had equal export and domestic sales. This confirms that the hi-tech sample is export-intensive competing in global markets, by developing innovative products and services. Chapter 8 performs an in depth analyses of the export performance of hi-tech firms.

6.4.6 Innovativeness of the Firms

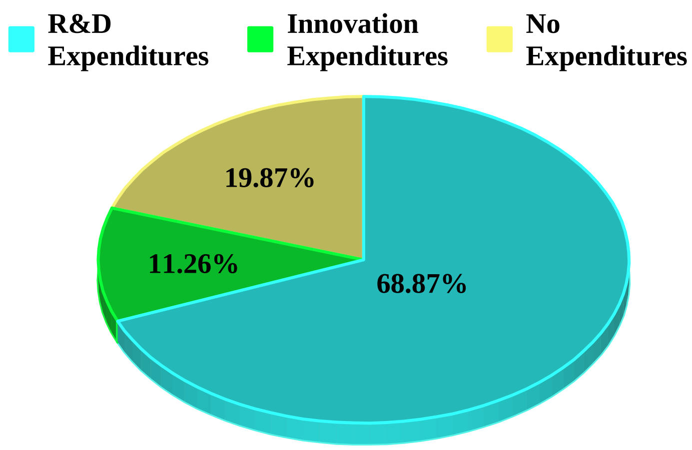
Different measures are used here to distinguish innovators from non-innovators. The fact that most academic studies tries to dichotomise firms as innovators and non-innovators, depending on the bases of observed outputs, is likely to be misleading, (Freel 2005). In the current context, the likely consequence is an underestimate of the differences between innovators and genuinely non-innovative firms (i.e. those not attempting to innovate). To overcome this, firms are categorised on a spectrum of low-tech to high-tech, in Table 6.4.

Table 6.4 Spectrum of Low-tech, Medium-tech and High-tech Firms

	Low-tech	Medium-tech	High-tech
Expenditures on Innovation	No Expenditures	Innovation expenditures	R&D Expenditures
New Product Development	No New Product	New Products in Pipeline	Launched
Patent Activity	No Patent Activity	Patent Filed	Patents Granted

The innovativeness of the hi-tech sample in terms of expenditures, new product development and patent activity are represented graphically in Figures 6.8, 6.9 and 6.10. Most of the firms in the sample level were innovative. With regards to expenditures, 80% of the firms had some sort of innovation expenditures of which 69% of the firms had R&D Expenditures alone, and 11% have innovation expenditures other than R&D. 19% of the firms have no expenditures at all (see Figure 6.8). The average spend on the R&D was 0.842 million and the average innovation expenditure was 1.22 million. Compared with the Scotland population, the Business Enterprise R&D (BERD) expenditure in 2003 for Scotland was £521 million and for UK was £13.69 billion whereas for this sample it was £127.17 million. About 49% of the workforce comprised of technicians & scientists.

Figure 6.8 Percentage of High, Medium & Low-tech firms in terms of Expenditures



With regards to innovation output, in terms of new product development in the last five years, 92% undertook new product development, of which 82% of the firms have new products on the market and 10% have new products in the pipeline (see Figure 6.9). 71.5% had revenue from new products launched in the past five years. The average number of new products launched was 20 and new products in pipeline, was 34.

With regards to patent activity, only 30% were patenting firms, the rest were not involved in patents (see Figure 6.10). This was due to the presence of firms involved in software in the composition of the sample, for which patents are irrelevant (though not copyright). Also the cost involved, did not justify patenting for many small new firms. There were 1220 patent applications filed in 2003 by firms in all sectors in Scotland, and the patents per £million R&D expenditure was 2.3 for Scotland, and for UK it was 1.5. In comparison, for the sample it was 8.72. The mean number of patents filed and granted was 7 and 4 respectively. This confirms the innovation-intense character of the Scottish hi-tech sector.

Figure 6.9 Percentage of High, Medium & Low-tech firms in terms of New Products

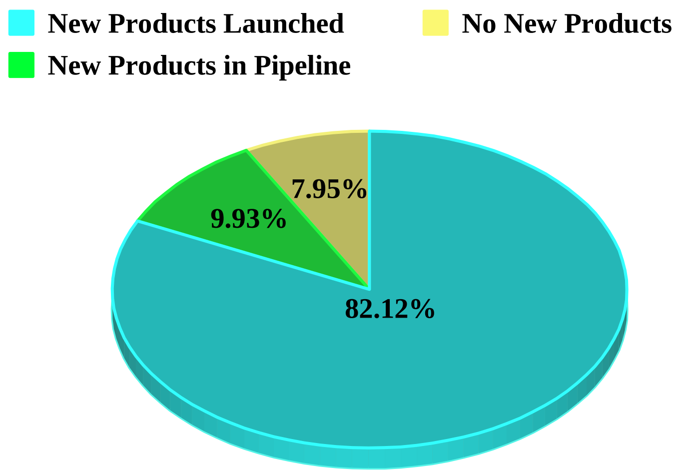
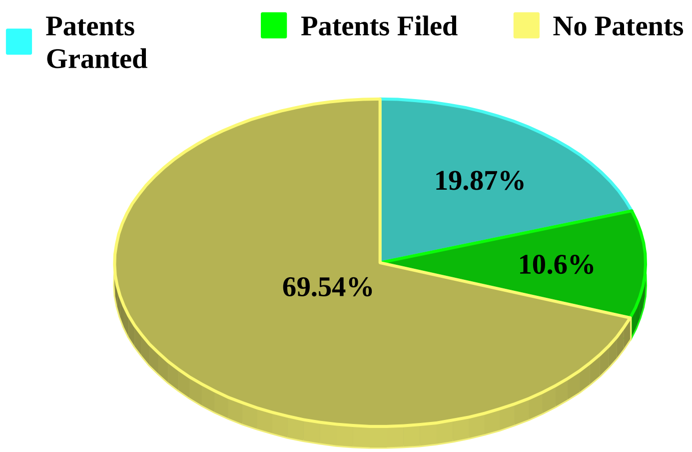


Figure 6.10 Percentage of High, Medium & Low-tech firms in terms of Patents



The firm's innovation input and output, relative to its size, is revealed next, by examining the number of firms that have non-zero innovation input and output in the different employment size group. Table 6.5 provides an overview of the innovation activity of firms, in each of the four size groups. The first two columns show the size group and number of firms in each group. The following eight columns represent the eight innovation categories. The first three relate to new product innovation, and columns 4 and 5 represents the patent activity. The last three columns represent the innovation input such as R&D expenditure, innovation expenditure and R&D department respectively. It reveals an interesting preliminary size-innovation relationship on examining each of the categories one by one.

Table 6.5 Innovation Activity by Firm Size

Firm Size	No. of Firms	Of which, Innovating Firms with:							
		New Product Sales 1	New Product Lau. 2	New Product Lau. &Pip. 3	Patent Granted 4	Patent Gr.& Fl. 5	R&D Exp. 6	Inno. Exp. 7	R&D Dep. 8
Micro	77	57	61	71	6	13	51	59	25
Small	55	45	47	51	13	21	38	44	24
Medium	10	6	7	8	5	6	7	9	6
Large	9	9	9	9	6	6	8	9	7
Total	151	117	124	139	30	46	104	121	62

Lau. =launched, Gr.= granted, Exp.=expenditures, Pip.= in pipeline, FL.= filed, Inno=innovation, Dep.= department

It is evident that, with respect to new product development, hi-tech firms are all innovation intensive irrespective of their size. More than 92% of the micro firms and small firms, 80% of the medium firms and all of the large firms were involved in new product development. With respect to innovation input, again a high percentage of firms reported incurring such expenditures. 66% of micro firms, 69% of small firms, 70% of medium firms and 90% of the large firms incurred expenditures that were earmarked as R&D expenditures. When it came to innovation expenditures a greater number of firms were involved in each size categories. Thus 77% of micro firms, 80% of small firms, 90% of medium firms, and all the large firms had incurred innovation expenditures. But with respect to patent innovation, it was more of a large firm activity, and the firms with patent granted and filed increases with size. Only 17% of the micro firms, 38% of small firms are involved in patents whereas, 60% of medium firms and 67% of large firms are involved in patents. The relationship between firm size and innovation is explored in detail in the chapter 7 on hi-tech performance. Moreover, the distribution of R&D expenditures by firm size and age of the sample is compared with that of the Scotland population in sections 6.4.7 and 6.4.8.

6.4.7 Distribution of R&D Expenditures Across Size

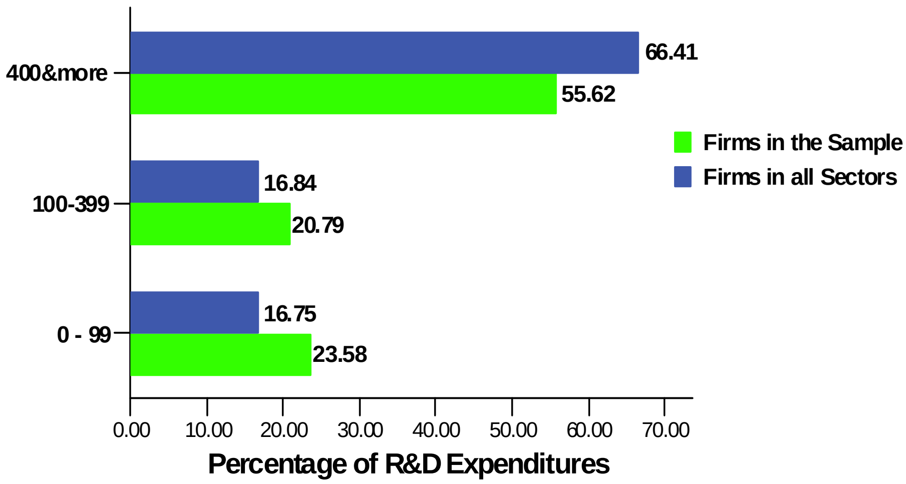
The R&D expenditure by firm size, for all sectors in Scotland in 2003 is given in Table 6.6. 66.41% of the R&D was performed by firms that have 400 employees and above, and the contribution by 0 to 99 employees and 100 to 399 employees are about 16% each.

Table 6.6 R&D Expenditures of firms in all sectors in Scotland by Size

	0 to 99	100 to 399	400 and above	Total
Manufacturing	7.20%	12.77%	64.55%	84.52
Service & others	9.55%	4.07 %	1.85%	15.48
Total	16.75%	16.84 %	66.41%	100

The contribution of firms in different size towards R&D expenditures is examined next, Figure 6.11 gives the comparison of the sample with that of the Scotland population. There is greater contribution by the small and medium firms in hi-tech sample compared to the firms in all sectors. Firms with 400 and more employees contribute 55.62%, and the contributions are 23% and 20% respectively, by the small and medium firms in the case of the sample. It implies that R&D input is extremely important to firms in the hi-tech sector. The χ^2 test to see if the R&D expenditures across firm size are the same for the Scotland population and the sample indicates no difference (test statistic of 5.45 is less than the critical value of 5.99, d.o.f. = 2, 5% significance).

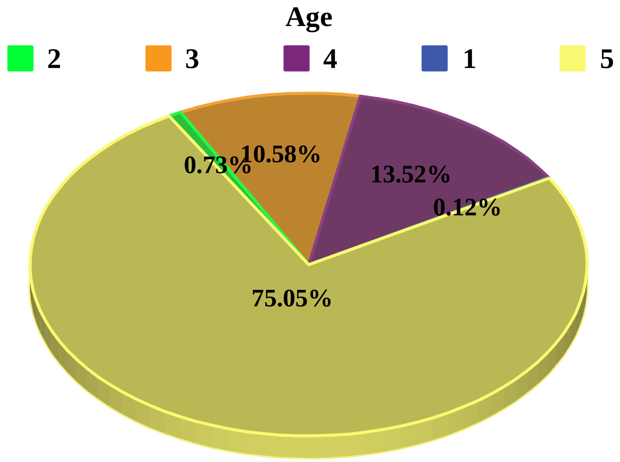
Figure 6.11 R & D Expenditures in firms by Employment-Size



6.4.8 Distribution of R&D Expenditures in firms by Age

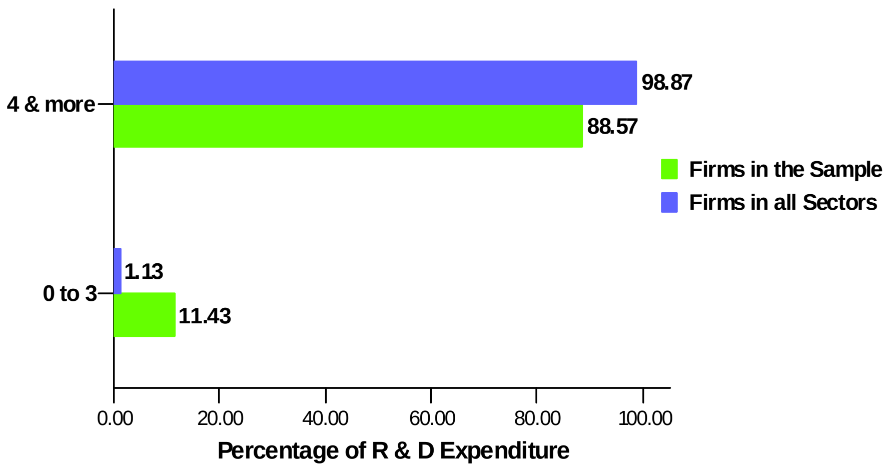
The age-wise distribution of R&D expenditures of the sample is shown in Figure 6.12. Three quarters of the R&D are attributed to the firms that are 5 years and older. The very young firms do very little R&D, contributing only 0.12%, and 44% do not have any R&D expenditures.

Figure 6.12 R&D Expenditure by Age



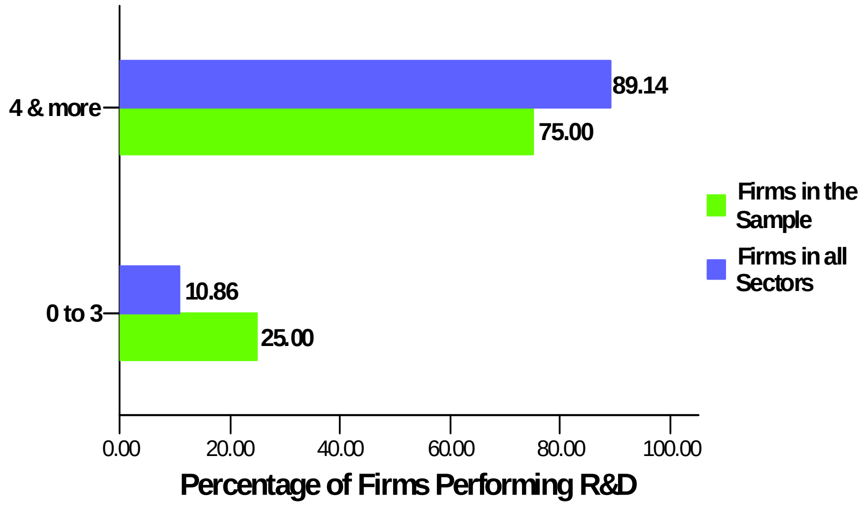
Comparison of the age-wise performance in terms of R&D spend with that of the Scotland population is given in Figure 6.13. The young firms in the sample have higher contribution to R&D (11.3%), as compared to firms in all sectors (1.13%). The χ^2 test (significant at 5%) confirms that R&D spent for hi-tech firms in different age-class are different from those in Scotland Population.

Figure 6.13 R&D Expenditures in firms by Age of Firm Comparison



Additionally the test to compare the percentage of firms having R&D expenditures in sample with that of Scotland population is also indicative that they do differ, (see Figure 6.14). χ^2 test static 20.64 exceeds the critical value of 3.84 (d.o.f. = 1, 5% significance), indicating that R&D spending is vital to firms of all age groups in the hi-tech sector. Young hi-tech firms contribute comparatively more with respect to R&D expenditures than the ones in other sectors.

Figure 6.14 Percentage of Firms having R&D Expenditures by Age



6.4.9 R&D Expenditure per Employee

The comparison of various industries R&D expenditure per employee in UK and Scotland for the year 2003 is presented in Figure 6.15. It is seen that all technology-based sectors in Scotland has very high R&D intensity, but still is lower than UK.

Figure 6.15 R&D Per Employee by Industry in Scotland & UK

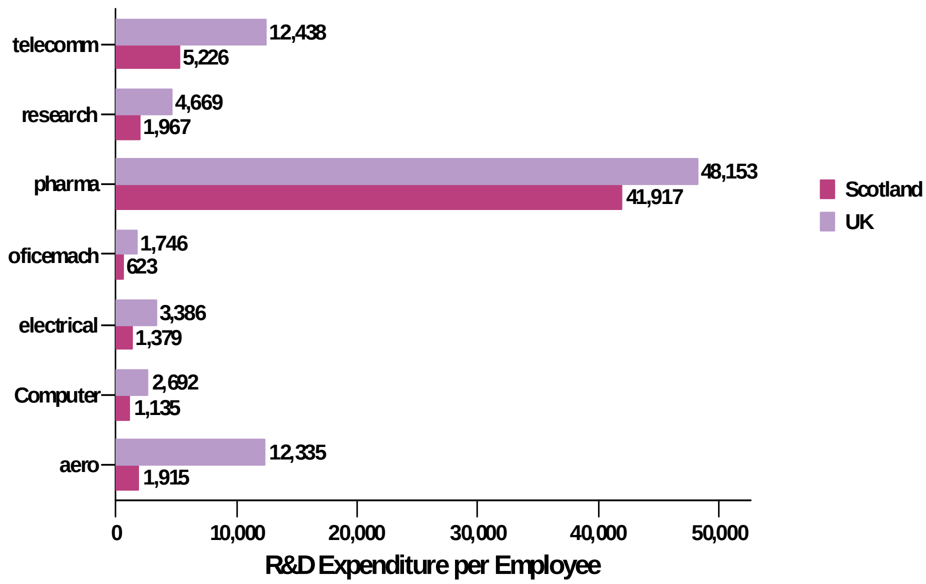
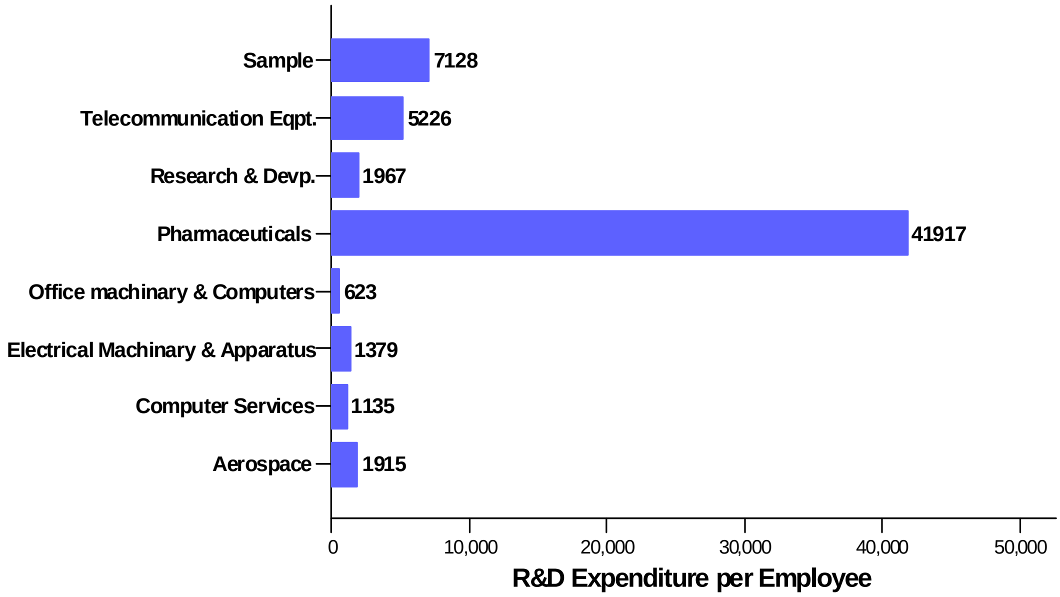


Figure 6.16 presents the comparison with the sample. It is seen that R&D per employee for the sample is 7128. It is quite high compared to other industry sectors, both in Scotland and UK. It is an indicator of the high intensity of innovation input of firm in the hi-tech sample.

Figure 6.16 R&D per Employee by Sector Comparison



6.5 Conclusion

This chapter set forth to describe the procedures adapted in formulation of the database that was used in this research on hi-tech firms in Scotland. First the method of multi-stage sampling techniques that was used in the identification of the final data was described in section 6.2. The various problems encountered in the process of identification of the final sample from the hi-tech population in Scotland and how it was solved was also examined in detail. Section 6.3 gave an overview of the final sample design. The statistical make-up and composition of the sample and how it compares with Scotland population was elaborated next in section 6.4 by analysing the key summary statistics. The preliminary analysis done on this data in the cross-sectional dimension enabled, in laying the ground work for further advanced analysis and econometric model, that was carried out in chapters 7, 8, 9 and 10. Further it reported on various key innovation variables and related these variables to firm characteristics, such as age, size and sector, by exploring the characteristics of the sample and by describing the R&D, patenting and product innovation behaviour of firms in it. Thus in this process the main characteristic features of the firms in the hi-tech sector are highlighted here.

Chapter 7 High Technology Firm Performance

7.1 Introduction

The performance of high technology firm has been one of the most significant subjects of attention of researchers and policy makers in recent times in the UK and in other advanced economies. The firms in the hi-tech sector face intense pressure to innovate and to perform due to high risk of failure, global competition, fast changing technology and rapid product obsolescence. One of the main objectives of this research is to assess the performance of Scottish hi-tech firms. Specifically, the economic and innovative performances of small and medium sized firms in comparison to large firms are analysed here.

This chapter aims to lay the basis for later chapters but also covers new ground in itself on the Shumpeterian hypothesis, and on Gibrat's Law. The analysis done in this chapter on growth and innovation, and on export performances in chapter 8, lays the ground for the applied econometric work in chapter10, where hi-tech performance, innovation and networks are analysed in a simultaneous equations framework. Section 7.2 reviews the empirical work on the relationship between size and the innovative performance of firms, and describes their innovation pattern, differentiated by size (Karlsson & Olsson 1998). It is analysed by regressions of a cubic function, permitting detection of inflection points and nonmonotonicity in the relationship. Various measures of innovative performance, that overarch the measurement of all stages, (from R&D, to patents and new product introduction to innovation sales) are used (Hagedoorn & Cloodt 2003). Section 7.3 examines the growth performance, by examining the growth in employment, turnover and productivity, differentiated by firm size. Specifically, the empirical relevance of Gibrat's Law of Proportionate Effect is investigated, by testing it on the hi-tech sample.

Many factors motivate this analysis. Highly dynamic, small, technology-based firms in the newly emerging technologies have been the central element of government policies in UK (Rominj & Albaladejo 2002), due to their capabilities not just in employment and income creation, but also in carving out specialised niche markets, innovative potential, industrial regeneration, productivity and competitiveness (Audretsch 1998; Becattini 1989; Camagni 1991; Steiner 1998; Piore & Sabel 1984; Brusco 1986; see chapters 1 & 2). Small firms are responsible for a disproportionately large number of technological innovations in industrialized nations (Pavitt et al. 1987) and in newly industrialized countries (Lee 1995). They are vital agents in the diffusion of technology (Pfirrmann 1998). Their unique know-how is based on the improvements they make to generic technologies developed elsewhere.

Policy applications of the endogenous regional development model, based on locally integrated SMEs, have been attractive to regional policy-makers due, to its proven capacity to generate jobs. This is in contrast to application of the exogenous development model where development is initiated by large firms from the outside, (Pottier 1988; Acs & Audretsch 1990; Maillat 1990). The role of large firms in regional development has declined due to their propensity to close plants irrespective of the local consequences. Also relevant is the fact that standardised production which is characteristic of the mature or declining phase of the product life cycle, contributes comparatively little to regional development. The importance of small firms, in contrast to large firms, in terms of their innovation performance has been widely debated in the past, and there have been two arguments. On the one hand are the Schumpeterians, who favour the large firms (Schumpeter 1950; Galbraith 1952), on the other are the proponents of classical theory, who favour SMEs (Acs et al. 1997; Rothwell & Zegveld 1982). This warrants further investigation.

Inspired by the Schumpeterian approach, although not aiming at matching the theoretical implications, a number of studies were conducted in the last three decades focused primarily on the relationship between growth (productivity) and innovation (R&D) and the effect of size. Although the vast amount of research differs considerably in terms of time periods, samples, data sources and methods, measures of innovative activity and business performance, a consensus emerged regarding the relation between size and R&D. Cohen and Klepper (1996) tried to summarize these findings into a number of stylized facts. Some of the most important of them are that the likelihood of engaging in R&D rises with firm size and approaches unity for the largest firms. Among the R&D performers, R&D rises monotonically but not more than proportionally with firm size. Among the firms carrying out R&D, the number of patents and innovations per dollar of R&D decreases with firm size and/or level of R&D. Among all firms, smaller firms account for a disproportionately large number of patents and innovations relative to their size. More recently, Klette and Kortum (2002) also made a summary of the stylized facts on the subject, stating that “R&D intensity is independent of firm size… Differences in R&D intensity across firms, are highly persistent” (p.5).

7.2 Innovative Performance and Firm Size

Schumpeter (1942) hypothesised that large firms are proportionately more innovative than small firms. This firm size/innovative activity hypothesis was fully developed by Galbraith (1952). Schumpeterian hypothesis maintains that there are economies of scale in technological innovation. Monopolistic market structures induce greater innovation than do competitive market structure, and large firms are able to monopolise the profits from innovation, to conduct even more R&D as compared to small firms, (Stinchcombe 1990). According to this view, larger firms achieve certain advantages from greater innovative activity. Firstly, capital market imperfections confer certain advantages on large firms in securing finance for risky R&D projects, because size is associated with the availability and stability of internally generated funds. Secondly, the scale of economies applies to industrial R&D. In addition, returns from R&D are higher in enterprises where the innovator has a large volume of sales, over which to spread the fixed costs of innovation. Finally, large firms also benefit from economies of scope as a result of complementarities between R&D and other activities (Barber et al. 1989). R&D is said to be productive partly because of the complementarities between R&D and other manufacturing activities, which are better developed in large firms compared to small firms. Researchers are more productive when they have numerous colleagues with whom to interact, and large groups also permit a greater functional division of labour. A large firm also has an advantage over small firms in R&D due to its superior ability to exploit the output of its research efforts. Based on these arguments, it is hypothesized that large firms generate more innovation.

On the contrary another strand of literature implies that the SME has an advantage in innovation (New Industrial Organisation, Acs et al. 1997; Acs & Audretsch 1991; Rothwell & Dodgson 1994; Tether 1998; Freel 2003). In terms of innovation per employee, small firms exceeds the efficiency of large firms due to their flexibility, agile, less hierarchy and creativity (Love & Roper 2002). Oakey et al. (1988) show that SMEs' share of all innovations since 1945 has increased, in contrast with Schumpeterian predictions. Acs & Audretsch (1990) find innovation is not stimulated by monopoly power or high concentration, though as an aggregate they spend less on R&D, they produce innovation with twice the productivity of larger firms. Bound et al. (1984) found that small firms had higher research productivity rate measured in patents compared to large firms. Pottier (1988) suggests that large firms often ignore innovative opportunities and seek to safeguard their existing monopolistic position. SMEs are actually not deterred from entering capital-intensive industries (Acs & Audretsch 1990), and persisting barriers to entry, can be reduced by networking (Camagni 1991).

Smaller firms are better at creating radical innovations because they better protect the innovator's property rights, as any innovation in large firms technically belongs to the firm, or at best to the team. This diffusion of property rights, along with bureaucratic inertia and other problems characteristic of large firms, dampen potential innovators' incentives to be creative (Acs et al. 1997). Cohen & Klepper (1996) proposed that small firms may be superior in the generation of new knowledge in industries characterised by technological opportunities. Larger firms are superior in their ability to appropriate returns from these innovations either by buying and selling property rights, through corporate ventures or benefiting through spillovers. Thus there are two diametrically opposed conclusions on the relationship between innovation and size.

7.2.1 Polynomial Functional Relation between Size and Innovation

The hypothesis relating to firm size and innovative activity has been empirically tested, by many suggesting widely diverging results. The size of firm has been alternately measured on the basis of employees, capital assets and sales volume and R&D intensity on the basis of R&D expenditure, personnel engaged in R&D, patents granted and sales associated with new products. But there is no consensus on what exactly is the relationship between firm size and innovative activity. Some studies use linear regression analysis or correlation and report a weak positive link between firm size and innovative activity, (Comanor 1967; Baldwin & Scott 1987).

Empirical evidence until the early 1970s suggested that the relation between size and volume of innovation assumed an s-shaped relation. Thus there was a low share by small firms, rising for medium and large firms and falling again in very large firms. In other words the relation is inverse-U shaped with respect to size and innovation intensity (first derivative of the s-curve) with a decline in large firms (Scherer 1984). The studies examining the relationship between firm size and innovation used R&D intensity, an innovative input, as a proxy for innovative activity (Scherer 1965). Fischer and Temin (1973) argue that the empirical analysis should be done between firm size and R&D output as a proxy for innovative activity. They find that elasticity of R&D with respect to size to be in excess of one, which does not necessarily imply an elasticity of innovative output with respect to size of more than one.

Size specified as a quadratic polynomial was tested by Grabowski (1968); Loeb & Lin (1977); Bound et al. (1984); Pavitt et al. (1987); Siddhartan (1988); Acs & Audretsch (1991); and Reid et al. (1996). The relationship between size and innovation is increasingly found to be U-shaped (Pavit et al. 1987). These indicate that very small firms and very large firms have proportionately higher R&D intensities and that the relationship varies across industries. Grabowski (1968) empirically tested the firm size and R&D intensity relationship for drug and chemical firms, and noted that the research intensity initially increased for the drug companies, but then declines for most of the relevant range of firm sizes. In the case of chemical firms, the research intensity increased proportionately with firm size. Mueller (1967), Kelly (1970), Loeb and Lin (1977) all report that research intensity is not positively correlated to firm size. While Mueller finds a negative relationship, Kelly observes no relationship at all. The study by Loeb and Lin analysed time series data (for 1961-72), which related sales to R&D expenditures for six major pharmaceutical manufacturers. They were observed to display a non-linear relationship. Small firms are more research intensive in the analyses by Rosenberg (1976) & Shrieves (1978). Bound et al. (1984) found that R&D intensity declined slightly with size among the smallest firms and then rose with size among the very largest firms, using a sample of American firms. Cohen et al. (1987), utilizing data from the Federal Trade Commission's (FTC) line of business programme, with due attention paid to industry effects, reported that firm size was not correlated to R&D intensity. Kumar and Saqib (1996) used probit and tobit models and observed from the probit model that firm size was positive and the quadratic term of firm size was negative, with both being significant. This implies that the probability of undertaking R&D increased up to a certain point, and then declined. The tobit model showed that firm size increases with R&D intensity in a linear fashion, with the quadratic term being insignificant. Subodh (2002), using probit and tobit models in the Indian context found no evidence to support the Shumpeterian hypothesis.

To summarise, past empirical research reveals that there are inter-industry differences in the relation between firm size and innovation effort, and between firm size and innovation output (Kamien & Schwartz 1975). With the exception of the chemical industry, most of the evidence does not support that innovation increases with size. It is seen that innovation effort increases more than proportionately with size, up to some point that varies from industry to industry. For still larger firms innovation intensity appears to be constant or decreasing with size. Beyond some magnitude, size does not appear conducive to either innovative effort or output.

7.2.2 Data, Variables and Model Specification

In this research the relationship between firm size and innovation is empirically investigated using a cubic polynomial with due consideration of the data. Moreover, this polynomial specification has the advantage of yielding easily interpretable results. By contrast the log-linear form of the regression equation cannot reveal inflection points or nonmonotonicity in the relationship between firm size and innovation intensity (Scherer 1965; Kamien & Schwartz 1975). Another attractive trait is that it allows one to determine easily, graphically as well as analytically, the empirically relevant value range for the underlying functional relationship.

Experiments with cubic polynomials which have been used in previous studies, (Soete 1979; Acs & Audretsch 1991) yielded statistically satisfactory results but no additional clues with regard to the role of scale economies, because the inflection points of the cubic curves lay outside the empirically relevant size range. Scherer (1965) by regressing R&D employment on firm size was able to check for non-linearities, and found a negative relation between firm size and innovation, and that it had an inflection point. He found that for smaller firms, firm size increases more than proportionately with innovative activity up to a certain threshold level, and then R&D intensity tends to decrease among larger firms.

In this chapter, different categories of innovation are used to represent the innovation activities of hi-tech firms. Chapter 6, section 6.4.6, on the innovativeness of the hi-tech firms, revealed that the participation rates in all innovation categories are high, irrespective of firm size, except for patent activity. A very high percentage of firms incur innovation expenditures, and are involved in product innovation, irrespective of size. But with respect to patent, it is more of a large firm activity. The distribution of innovation activity across firm size is given in Table 7.1. Category 1 and 2 gives the mean value of new product sales in last five years, and the innovation expenditures, respectively. Category 3 and 4 report the mean count of new product launched, and in pipeline, respectively. Categories 5 and 6 represent mean patents granted and filed, respectively. It is seen that the mean is highest for largest firms. However, a non-linear relationship is evident here. The innovation-size relations are graphically represented in Figures 7.1 to 7.6.

Table 7.1 Key Innovation Indicators by Size Class

Size Class	No. of Firms		Innovation Category: Value in Millions: 1 New Product Sale	2 Innov. Exp.	Counts: 3 New Product Launched	4 New Product Pipeline	5 Patent Granted	6 Patent Filed
Micro 1-9	77	Mean % Total	.096 0.60%	0.060 2.5%	6.53 17.0%	22.56 33.6%	0.17 2.0%	0.52 3.6%
Small 10-99	55	Mean % Total	.637 3.1%	0.685 20.5%	18.09 33.6%	27.11 28.8%	2.18 18.7%	7.4 36.8%
Medium 100-499	10	Mean % Total	5.57 4.9%	3.37 18.3%	7.4 2.5%	28.4 5.5%	3.9 6.1%	9.8 98.9%
Large 500 & more	9	Mean % Total	116.32 91.4%	11.97 58.6%	154 46.9%	184.56 32.1%	52.11 73.2%	62.44 50.8%
Total	151	Mean Sum 100%	7.68 1144 100%	1.22 183.7 100%	19.59 2958 100%	34.26 5173 100%	4.25 641 100%	7.33 1107 100%

Innov. = Innovation, Exp. = Expenditure

Figure 7.1 No. of Patents

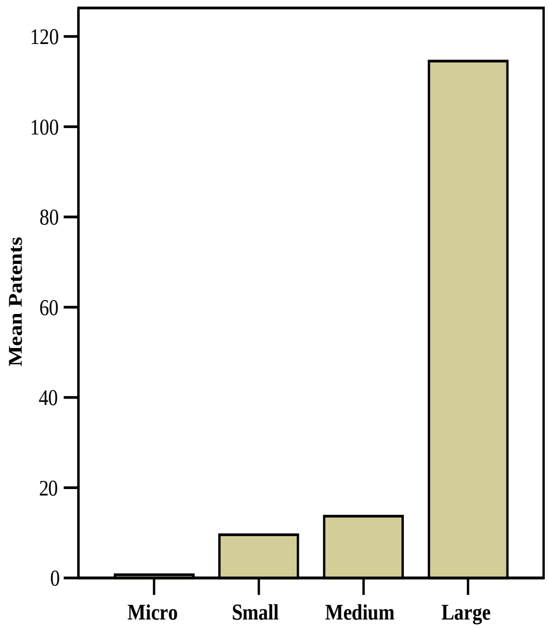


Figure 7.2 Patents Intensity

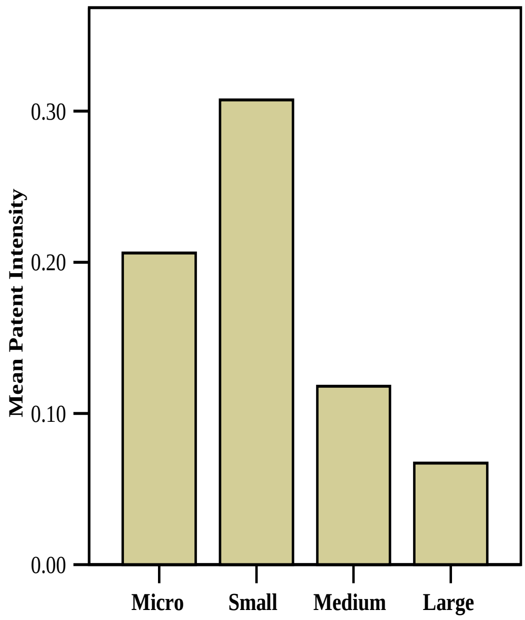


Figure 7.3 No. of New Products

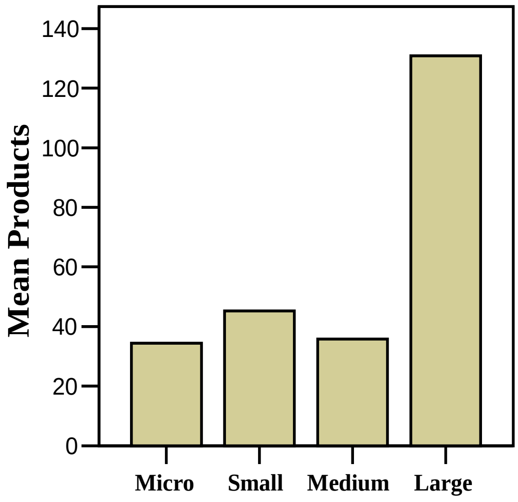


Figure 7.4 New Product Intensity

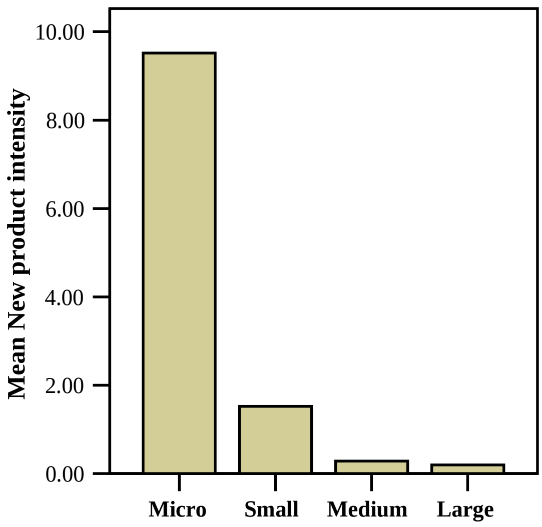


Figure 7.5 Innovation Expenditure

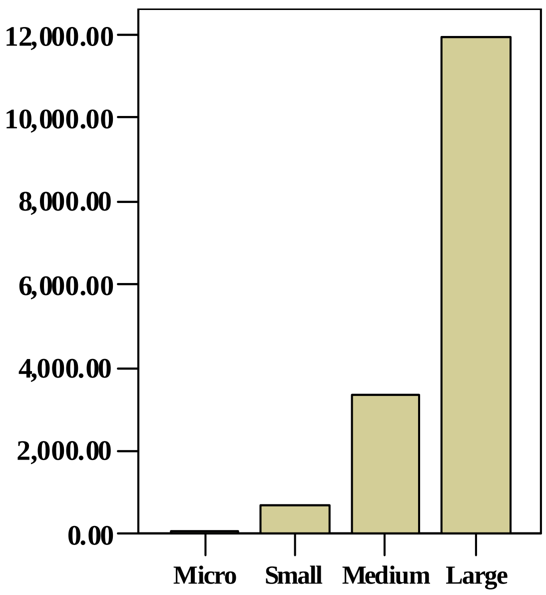
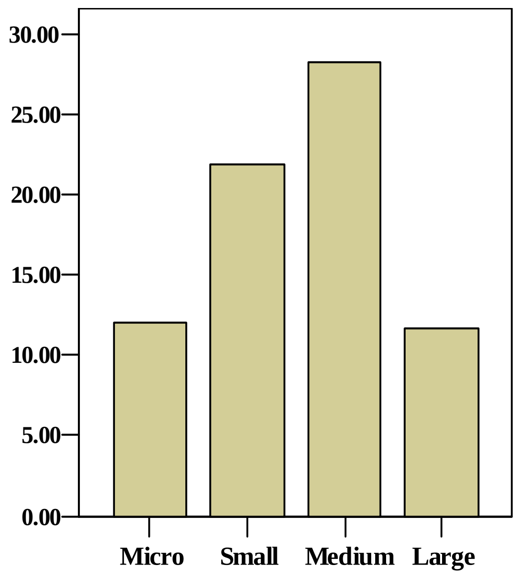


Figure 7.6 Expenditure Intensity



It is seen that the new product and patent counts, and innovation expenditures are all higher for large firms compared to the small and medium firms. But, the intensities (innovation activity deflated by a measure of firm size) are higher for the SMEs in the case of new product intensities (Figure 7.4), patent intensities (Figure 7.2) and expenditure intensities (Figure 7.6), but not for innovation sales intensity. Moreover, a non-linear relation between firm size and innovation is seen. One way of taking this into account, which embraces the Schumpeterian hypothesis, is to estimate a cubic polynomial, which explains innovation by firm size. This is estimated using cross-section data on firms spanning the 5 hi-tech sectors, in this research, viz. life sciences, optoelectronics, digital-media, microelectronics, and software. The model is specified as a cubic function (Soete 1979; Acs & Audretsch 1991) of the following form:-

$$Innovation = b_0 + b_1 (Size)^1 + b_2 (Size)^2 + b_3 (Size)^3 \qquad 7.1$$

where, size is measured by number of employees and innovation activity by any one of different measures. The innovation activity is also deflated by a measure of firm size (either employment or sales) to obtain an index of 'innovational intensity'. Both innovation inputs as well as innovation outputs, are used to estimate this cubic functional relation between size and innovation of hi-tech firms. The data runs across service, manufacturing and developmental small, medium and large firms. The firms with no innovations are not included, as the focus here is on:

- the innovation input and output of firms in relation to firm size,
- the degree to which the innovation intensity of firms differ with size,
- all within the hi-tech context.

7.2.2.1 Variables

Innovation-counts, innovation-values and innovation-intensities are used to explain the relation between size and the innovation activity of hi-tech firms. The innovation variables used in the estimation, and their definitions, are all presented in Table 7.2. Product innovations (new product launched & in the pipeline), and patents granted and filed are the innovation output measures used in the estimation. Thus both the innovation levels of the firm as well as the future potential innovation levels are accounted for. The drawback of all indicators based on 'counts', be it patents or numbers of new products, is that all innovations are valued equal by this. It focuses on both the technical aspects of innovation and the introduction of new products into the market, but it excludes the possible economic success of innovations as such (Crepon et al. 1997; OECD and Eurostat 1997). To accommodate the latter point, the revenue from new products and services, and the new product sales in the past five years per employee are also included.

Innovation expenditures, innovation expenditure intensity and R&D productivity (as the ratio of total sales to R&D staff in the firm) are the innovation input measures used in the estimation of the model. Innovation expenditures is interpreted here as including R&D and other expenditures such as for training, licensing and near market activities. As mentioned in Chapter 2, section 2.5, there are drawbacks to using R&D as the only innovation input measure. It does not capture all aspects pertinent to innovation, and R&D related inputs account for a minority of innovation expenditures, varying from 15-50 percent depending on the sector being studied, (Felder et al. 1996). Near market innovation activities are not captured by it, (Brouwer & Kleinknecht 1997) and especially innovation activities of SMEs (as well as service sector firms) are heavily underestimated, (Kleinknecht 2000). This data mainly constitutes SMEs, as 94% of the sample is SMEs, as is typical of the size distribution of firms. The sample frame deals with start-ups (6% of the firms are under two years, since inception), developmental (6.4%), and service firms, hence, innovation expenditure measure is used.

Table 7.2 Definition of the Innovation Variables

Innovation Output	
Innovation Count & Volume	***Innovation Intensities***
Patents Patgran - Patent granted Patefile - Patents filed	Patgraint - Patent granted intensity *(per sales)* Patfilint - Patent filed intensity *(per sales)*
Product Innovation Prdlaun - New Products Launched Prdpipe - New Products Pipeline Innsale - New Products Sales	Prdlauint -New Product launched intensity *(per sales)* Prdpipint - New Product pipeline intensity *(per sales)* Innsalint - New product sales intensity *(per employee)*
Innovation Input	
Innovation Volume	***Innovation Intensities***
Innexp - Innovation Expenditures	Inexpint - Expenditure Intensity *(per employee)* Rdpdty - R&D Productivity *(sales to R&D staff ratio)*

7.2.3 Estimation Results

A non-linear relation between innovation intensity and firm size are determined and represented graphically and analytically in this section. The results of the estimation of the models are given in Table 7.3 and 7.4. The Figures of the estimated cubic function for the variables are presented in Figures 7.7 to 7.10. This enables one to identify the specific employment size at which there is maximum and minimum innovation output and input by high technology firms. The estimation results are discussed in the following sections enabling one to examine the effects of size on product innovation, patent activity, value added from innovation and lastly innovation input in hi-tech firms.

i) Innovation Counts and Innovation Volume

The estimation results with respect to: innovation counts (patent counts and new product counts); and innovation volume (innovation expenditure and innovation sales) is discussed initially (see Table 7.3). The equations estimated are highly significant overall providing a good overall fit to the data (F-statistic is significant at 1% level for all equations). The coefficients for the variable, firm size (b_1) is positive, the quadratic term size-square (b_2) is negative, and the cubic term size- cube (b_3) is positive, for all the estimations in Table 7.3.

Table 7.3 Estimation Results - Innovation Count & Volume

Dependant Variable	R^2	F	Sig.	b_1			b_2			b_3		
				Coeff.	*T*	*Sig. T*	*Coeff.*	*T*	*Sig. T*	*Coeff.*	*T*	*Sig. T*
Patgran	.88	361.1	.000	.0714	8.856	.000	-5.31E-05	-8.467	.000	9.96E-09	10.29	.000
Patfile	.54	58.17	.000	.1004	4.450	.000	-6.84E-05	-4.249	.000	1.18E-08	4.766	.000
Prdlaun	.79	182.6	.000	.0829	2.070	.040	-6.99E-05	-2.245	.026	1.86E-08	3.869	.000
Prdpipe	.39	32.03	.000	.1411	1.489	.138	-1.14E-04	-1.551	.123	2.50E-08	2.203	.029
Innsale	.72	126.2	.000	119.7	5 .275	.000	-0.530	-3.004	.003	9.17E-06	3.370	.001
Innexp	.45	40.86	.000	26.39	7.853	.000	-.0122	-4.702	.000	1.40E-06	3.475	.000

The coefficients are significant at 1% for all except for the (*prdpipe*) products in pipeline, where only the cubic term size-cube (b_3) is significant (at 5% level). Robust results are obtained for all the different innovation variables. These results hold even after removing the outliers, at both lower and upper scales. The maximum, minimum and point of inflections are presented in Table 7.5. The number of new products launched and in the pipeline is seen to increase with firm size for small firms. It reaches a maximum at around 900 employees size after which it is seen to decrease with increasing size up to a point, where the innovation is at its minimum. Beyond this size the number of new products increases with size for very large hi-tech firms, as is evident from Figure 7.8. The employment size at maxima is 963 and 857 for new products and in pipeline, respectively, and the employment at minima is 1542 and 2164 respectively.

Figure 7.7

No. of Patents Granted

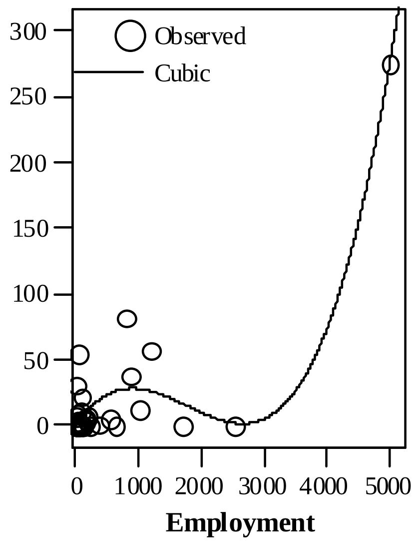


Figure 7.8

No. of new products in the Pipeline

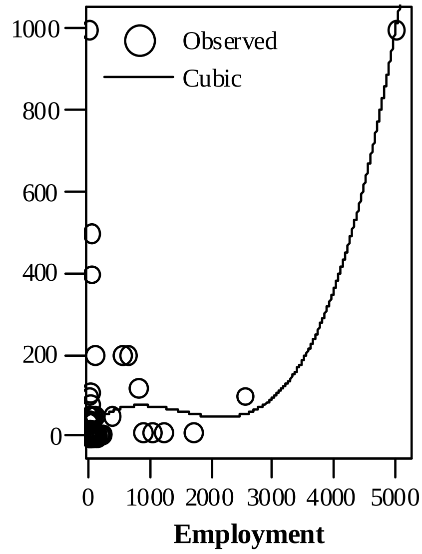


Figure 7.9

Innovation Sales Intensity

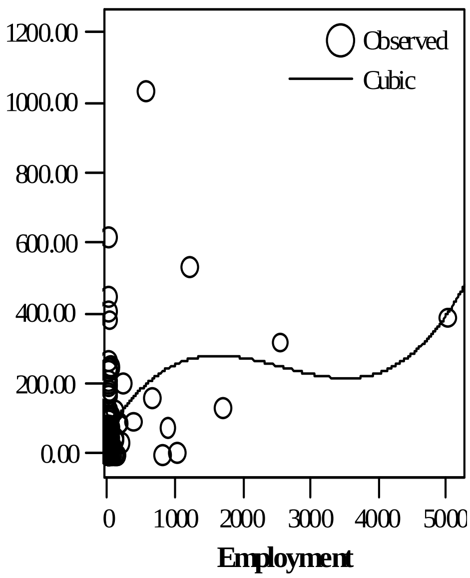
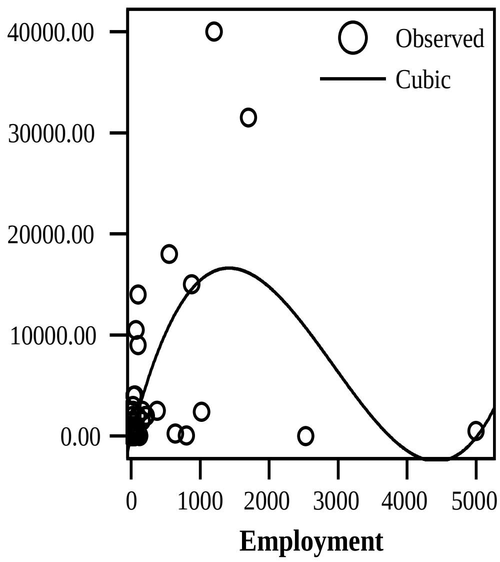


Figure 7.10

Innovation expenditure



In the case of patents, not many small firms undertake patenting due to the high costs involved and uncertainties in the process, it is more of a large firm thing. But of the patenting firms, the evidence reveals that the number of patents granted and filed is seen to increase for the small firms until a maximum number of patent granted and filed is observed at 900 and 986 employment size, respectively. After this size, the number of patent granted and filed decreases with increasing size until a minimum is observed at 2653 and 2863 respectively (see Table 7.5). It is found to increase beyond this size only for very large firms (see Figure 7.7). All coefficients are significant at 1%, (see Table 7.3). This is true in the case of volume of innovation also. All three coefficients are significant at 1% for both the volume of innovation output, i.e. innovation sales (*innsale*), and also the volume of innovation input, i.e. innovation expenditures (*innexp*) (see Table 7.3).

ii) Innovation Intensity

The estimation result in Table 7.4 deals with product innovation intensity, patent granted and filed intensity, and innovation input intensities. The results indicate that innovation intensity increases with firm size for small firms and reaches a maximum, after which it is seen to decrease with increasing size up to a point, where the innovation is at its minimum. Beyond this size the number of innovation intensity increases with size for very large hi-tech firms. This relationship is seen for patent intensities (both *patgraint* and *patfilint*), innovation sales intensities (*innsalint*) and R&D productivity (*rdpdty*). However, this relationship does not hold in the case of product innovation intensities.

Table 7.4 Estimation Results - Innovation Intensity

Dependant Variable	R^2	F	Sig.	b_1 Coeff.	b_1 T	b_1 Sig. T	b_2 Coeff.	b_2 T	b_2 Sig. T	b_3 Coeff.	b_3 T	b_3 Sig. T
Patgraint	.123	6.189	.000	1.21E-04	4.072	.000	-7.72E-08	-3.344	.001	1.06E-11	2.980	.001
Patfilint	.082	3.949	.009	1.11E-04	3.302	.001	-7.22E-08	-2.778	.006	1.00E-11	2.494	.013
Prdlauint	.002	.065	.951	-1.9E-04	-.423	.673	1.03E-07	.295	.768	-1.39E-11	-.2575	.780
Prdpipint	.004	.1861	.905	-7.5E-04	-.622	.535	4.34E-07	.464	.643	-5.92E-11	-.410	.670
Innsalint	.380	8.229	.000	.3255	2.786	.000	-1.46E-04	-1.611	.109	1.89E-08	1.353	.178
Innexpint	.004	.219	.882	.0149	.477	.634	-1.38E-05	-.566	.572	2.03E-09	.540	.580
Rdpdty	.133	6.318	.000	1.113	3.955	.000	-7.28E-04	-3.342	.001	1.04E-07	3.126	.002

The estimated equations show a good overall fit for the two patent intensities, innovation sales intensity and R&D productivity equations. F-statistic is significant at 1% level for these four estimations, but not for product launched (*prdlauint*) and products in pipeline intensities (*prdpipint*) and innovation expenditure intensity (*innexpint*). The coefficients for the firm size (b_1) is positive, the quadratic term size-square (b_2) is negative, and the cubic term size-cube (b_3) is positive for all the estimated equation in Table 7.4, except in the case of product innovation intensities, *prdlaunt* and *prdpipint*. The coefficients are significant at

1% for both patent granted and filed intensity equations, and also for the innovation input intensity measured as R&D productivity (see Table 7.4). The employment size at maxima is similar to that of innovation counts and the size at minima is at a slightly higher employment size, around 3800 (see Table 7.5).

Table 7.5 Maximum, Minimum & Point of Inflection

	Employment at		Point of Inflection
	Maxima	Minima	
1. New Products Launched	963	1542	1252
2. New Products in Pipeline	867	2164	1515
3. No. of Patents Granted	900	2653	1777
4. No. of Patents Filed	986	2863	1925
4. Innovation Expenditures	1417	4431	2924
5. Innovation Sales Intensity	1637	3492	2561
6. Patent Granted Intensity	982	3866	2424
7. Patent Filed Intensity	959	3856	2407
8. R&D Productivity	966	3659	2313

iii) Conclusion

The overall results thus support the Shumpeterian hypothesis but only at very high scales. At lower scales there is an optimal size, supporting small size advantage in innovation. Small firms are sometimes growing on to achieve Shumpeterian size. Thus one has a kind of local equilibrium, in which small firms seem to have an innovation advantage; but aggressive, high growth firms can jump to higher innovation intensities at much larger scale, and enjoy large benefits of increasing returns. This result thus encompasses both the notion of an optimal small firm size, and the Schumpeerian hypothesis. Once the higher growth firms have achieved the scale necessary for the Schumpeterian effect to take hold, they start to generate effects analysed in endogenous growth models, for which expansion, innovation, then further expansion are mutually reinforcing. See the treatment in Reid's (1989) analysis of classical economic growth. However, it should be noted here that the relation between innovation and size is analysed only for firms with positive innovation. It is not proper to ignore those firms that have zero innovation output and input. This point is addressed in chapter 10, where, a 4-equations simultaneous model with correction for sample selection is used to understand the innovation process. Here size is an explanatory variable in the equations determining innovation decision, innovation input, and innovation output.

7.3 High Technology Firm Growth Performance

This section analyses the growth performance of hi-tech firms by focussing on the growth in turnover, employment and labor productivity. The survey instrument has made available the data on turnover, employment and labor productivity (ratio of turnover to employees) of firms for all the years from 1999 to 2003. Table 7.6 presents the mean of employees, turnover and productivity in these five years, for the whole sample and differentiated by size, (standard deviations in parenthesis).

Table 7.6 Scale of High Technology Firms

Year	2003	2002	2001	2000	1999
Turnover in millions					
Size \ No.	150	137	119	104	88
Mean	66.31 (92.92)	65. 64 (97.26)	75.14 (104.1)	74.25 (90.95)	74.99 (99.81)
Micro	59.09 (100.3)	59.18 (113.4)	85 (96.61)	60.06 (77.23)	54.09 (71.96)
Small	58.9 (48.59)	61.35 (50.20)	79.30 (89.07)	81.03 (99.93)	85.77 (121.2)
Medium	85.77 (18.88)	67.92 (37.30)	60.31 (40.48)	56.36 (41.57)	65.75 (34.14)
Large	150.9 (193.8)	135.4 (177)	145.96 (209.6)	138.55 (130.6)	139.1 (132.7)
Employees					
No.	151	141	128	111	95
Mean	118.1(497)	142.52 (671.8)	169.29 (855)	194.52 (953.67)	237.02 (1122)
Micro	3.95 (2.52)	3.82 (2.75)	3.56 (2.73)	3.64 (3.23)	3.70 (3.84)
Small	28.39 (20.58)	28.52 (28.44)	27.24 (28.75)	26.34 (28.02)	29.81 (20.37)
Medium	165.8 (85.44)	150.6 (83.09)	128.5 (91.93)	119.89 (86.42)	124.14 (58.5)
Large	1590 (1419)	1868 (2069)	2087 (2671)	2396 (2879)	2551 (3194)
Labor Productivity					
No.	150	139	126	110	94
Mean	13.98 (70.93)	14.61 (71.74)	17.26 84.59	22.15 (104.3)	26.56 (120)
Micro	0.29 (0.79)	0.35 (0.14)	0.29 (0.85)	0.26 (0.53)	0.24 (0.61)
Small	1.82 (2.49)	1.72 (2.52)	1.78 (2.69)	1.79 (2.85)	1.76 (2.53)
Median	14.88 (10.12)	11.53 (10.88)	9.18 (10.42)	8.66 (9.37)	8.99 (7.31)
Large	203.1 (224.7)	200.47 (216.60)	19.85 (248.68)	83.56 (291.2)	95.18 (319)

It is seen that there is no significant difference in the means over the five years. An ANOVA test of equality of means is not rejected for turnover, employee and labor productivity over the five years, for the full sample and by size class. In addition, the percentage changes in these three measures also indicate a similar trend. Ten growth rates for the various years are computed for each of the three measures, (see Table 7.7).

Table 7.7 Mean Growth Rates

Year	Turnover Growth			Employment Growth			Labor Productivity Growth		
	No.	Mean	Std. Dev.	No.	Mean	Std. Dev.	No.	Mean	Std. Dev.
2003-2002	128	9.98	53.95	141	1.25	55.82	137	2.73	51.76
2003-2001	116	-4.47	131.57	128	3.14	67.14	114	-31.99	184.87
2003-2000	100	-7.85	135.07	111	3.51	66.63	99	-36.34	202.31
2003-1999	85	-.99	131.18	95	-2.12	80.18	84	-29.58	225.99
2002-2001	114	-5.29	81.516	127	7.83	30.29	113	-21.64	111.28
2002-2000	98	.26	80.00	110	10.39	39.05	98	-17.763	112.44
2002-1999	85	9.00	78.35	95	8.02	52.11	84	-15.60	158.62
2001-2000	97	3.76	57.70	110	7.38	29.98	97	-2.52	56.68
2001-1999	85	14.27	67.68	95	7.63	44.80	84	.61	99.66
2000-1999	84	17.12	39.90	94	6.43	33.45	83	5.24	66.79

It is seen that the employment growth rates were not significantly different for all ten years. The growth in turnover and labor productivity was also not significantly different except for the years 2003-2002, 2002-2001, 2001-2000 and 2000-1999. In these years the firms grew at different rates, the ANOVA test is significant for the turnover growth (F=2.438, sig.=.064) and labor productivity growth (F=2.846, sig.=.037). But it is difficult to examine the trends using aggregate data given the heterogeneity of firms across size. As is evident in Table 7.6, there exist significant differences in these scale measures across firm size.

Moreover, the growth rates for turnover and employment are much higher for the micro, small and medium sized hi-tech firms compared to their larger counterpart. Figures 7.11 to 7.13 represent the turnover, employment and productivity growth for different periods, by firm size. The picture that emerges here is that there exists a negative relation between firm size and growth, where the smaller hi-tech firms perform better with respect to growth in turnover, employment and productivity, compared to large firms.

Figure 7.11 Turnover Growth by Size

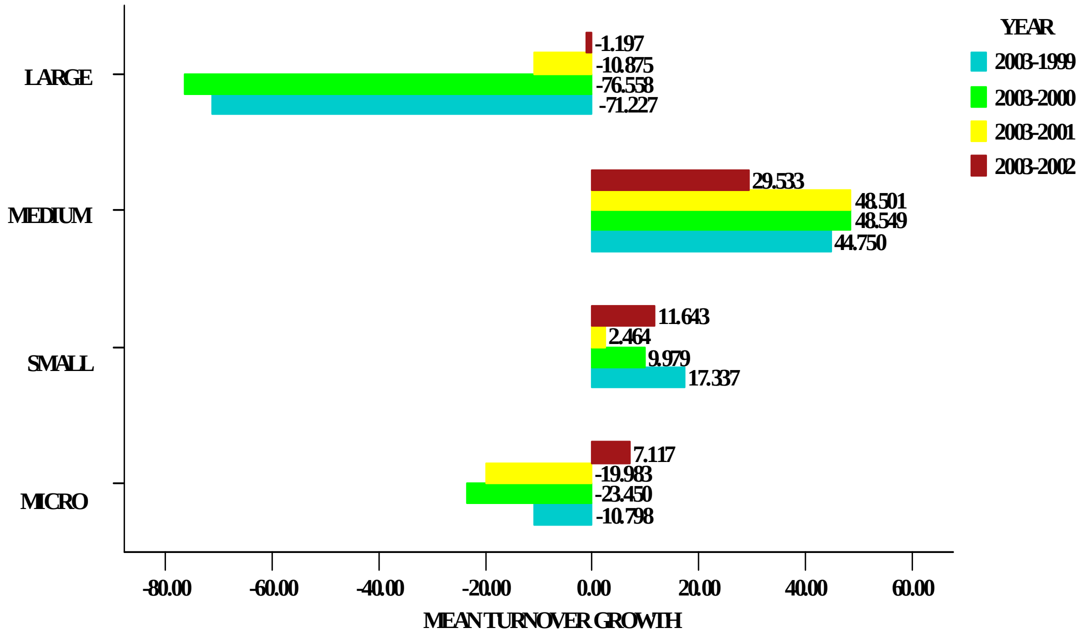


Figure 7.12 Employment Growth by Size

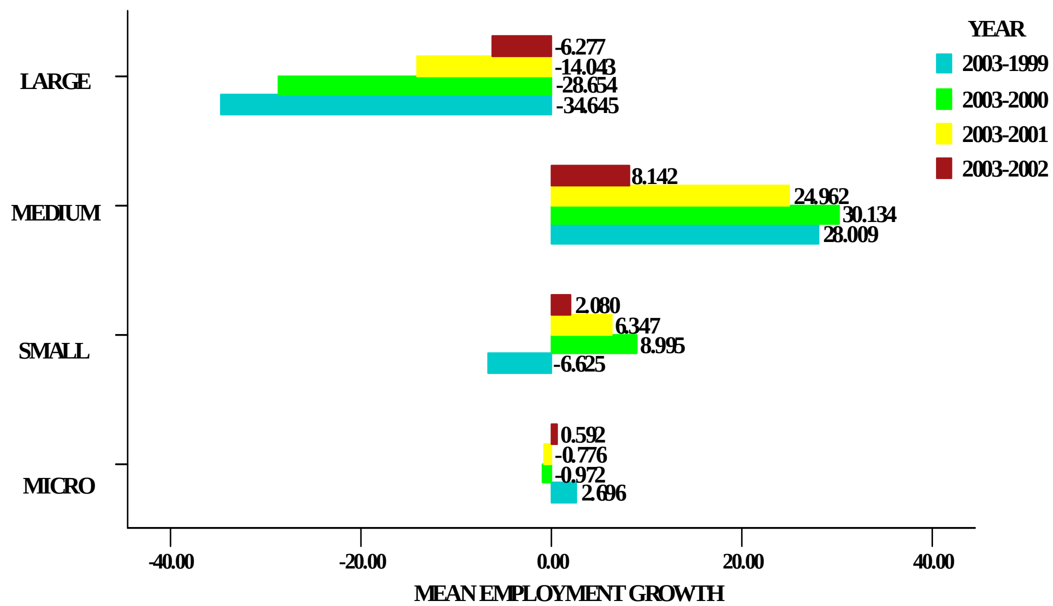
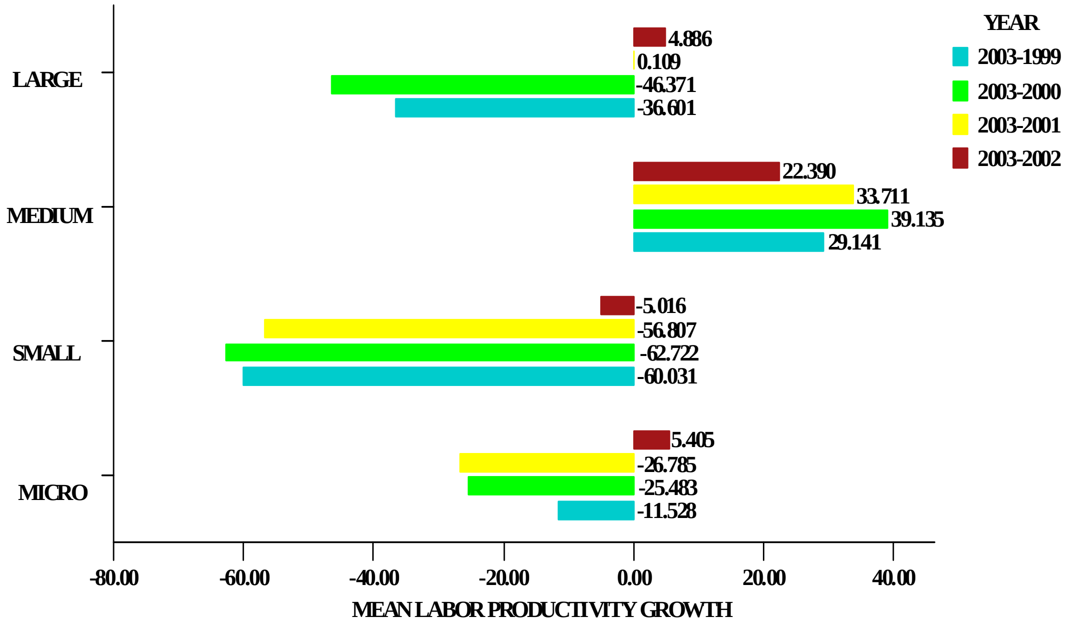


Figure 7.13 Labor Productivity Growth by Size



These preliminary findings are compatible with the estimation results of the test of the Gibrats law examined in section 7.3.1, where the firm size-firm growth relation is further explored by testing the Gibrat's Law of Proportionate Effect (Singh & Whittington 1975; Hall 1987; Dunne & Hughes 1994; Sutton 1997; Reid 2007).

7.3.1 Test of Gibrat's Law of Proportionate Effect

The Gibrat's law of proportionate effect, as applied to businesses, states that firm growth rates are independent of firm size. The exposition of models below follows Reid (2007, ch. 16) A more general form, which embraces this is:

$$S_{t+t} / S_t = \gamma S_t^{(\tilde{\beta}_1 - 1)} \qquad 7.2$$

where S is size and γ is the exogenous deterministic effect (market growth rate). When β=1 Gibrat case occurs and the above equation collapses to equation 7.3.

$$S_{t+t} / S_t = \gamma \qquad 7.3$$

In this instance, all firms grow at a common market rate γ. Then the growth is independent of size. When β>1 larger firms have higher growth rates than smaller ones and when β<1 smaller firms have higher growth rates than larger firms. There is conflicting evidence, for and against Gibrat's law. Empirical studies in the past supported Gibrat's law in the US (Simon & Bonini 1958) and UK (Hart 1962; Sutton 1997). Singh & Whittington (1975) found a positive relation, where larger sized firms grew more rapidly than smaller sized firms in the UK. Nevertheless, rather than a positive relation between rate of growth and firm size, a negative relationship between firm growth and firm size were reported in many subsequent work both in the US (Mansfield 1962; Evans 1987; Hall 1987; Dunne et al. 1989a) and in UK (Reid 1993, 2001; Dunne & Hughes 1994; Hart & Oulton 1996).

However, the analysis of growth rate by firm size based on surviving firms alone meant that there would be a bias towards an inverse size-growth relation. Mansfield (1962) in test of the Gibrat's law reported that small, slow growing firms were more likely to fail than large, slow growing firms. By taking this into account, attempts have been made to solve for sample selection bias in the past (Hall 1987; Reid 1993; Dunne & Hughes 1994), but did not find any different results. In general, Gibrat's law does not hold at least for small firms in the US and UK. Size, was found to be inversely related to growth, implying that small firms grew faster than large firms. The fact that, it may hold for large firms, is supported by few (Singh & Whittington 1975; Hall 1987; Dunne & Hughes 1994; Hart & Oulton 1996).

In general, the results are found to be sensitive to the estimation method, the functional relationship and the measure of size adopted to test the Gibrat's Law (Heshmati 2001). As in Reid (2007, ch. 16) equation 7.3 can be extended by multiplying it by an independently distributed positive random variable $u_t > 0$ giving

$$S_{t+t} / S_t = \gamma S_t^{(\tilde{\beta}_1 - 1)} u_t \qquad 7.4$$

The log-linear expression of the equation 7.4 is used for the purpose of ease of estimation.

$$\text{Ln } S_{t+t} = \text{Ln } \gamma + \beta \text{Ln } S_t + \text{Ln } u_t \qquad 7.5$$

or

$$s_{t+t} = \alpha + \beta s_t + \varepsilon_t \qquad 7.6$$

where $\text{Ln } S_{t+t} = s_{t+t}$, $\text{Ln } \gamma = \alpha$, $\text{Ln } S_t = s_t$ and $\text{Ln } u_t = \varepsilon_t$

Equation 7.6 is estimated as

$$s^e_{t+t} = a + bs_t \qquad 7.7$$

where e denotes the expected value of the dependent variable, and (a, b) are regression estimates of (α, β). Equation 7.7 is an expression for the first order linear difference equation for which the stability condition is 0<b<1. If this condition holds then the sequence s_t converges to an equilibrium value of s*. Equillibrium is achieved when

$$s^e_{t+t} = s_t = s^* = a/(1-b) \qquad 7.8$$

The OLS estimates of the equation are obtained for values of S_{t+t} and S_t using three different measures of scale, natural log of turnover (lnturnx), natural log of employees (lnempx), and natural log of labor productivity (lnlbprx), where 'x' represents the five different year from 1999 to 2003: 3 for 2003, 2 for 2002, 1 for 2001, 0 for 2000 and 9 for 1999. Four estimates are carried out for each of turnover, employment and productivity, respectively. The four growth rates involves the five years from 2003-1999. It is for:- two 3-year, and two 2-year periods. Robust results are attained from the 12 forms of estimation.

7.3.2 Estimation Results and Discussions

The estimation results for turnover, employment and productivity growth are presented in table 7.8, 7.9 and 7.10 respectively. The null hypothesis of H_0: β=1 is rejected for all 12 regressions. All of the estimation results are significant at 1%. Moreover, β < 1 in all regressions for all estimations implying that smaller hi-tech firms have a higher growth rate compared to larger hi-tech firms. The equilibrium values are provided in the last two columns of Tables 7.8. 7.9 and 7.10, expressed in terms of both the natural logarithm, $\mathbf{s_t^*}$, and in absolute value St*. The latter are calculated by taking the exponential value $\mathbf{s_t^*}$. It is seen from the last two columns of Tables 7.8, 7.9 & 7.10 that the equilibrium state is reached for small sized firms.

Table 7.8 Estimation Results- Turnover Growth

Estimation	*Dep. var*	*Indep. var*	*Const. a*	*Coef b*	*T Test b=0*	*p-value*	*N*	*R2*	*F Test b=1*	*p-value*	s_t^*	St* in millions
1	lnturn3	lnturn1	1.247	.843	23.37***	.000	112	.8323	18.8***	.000	7.96	2.86
2	lnturn3	lnturn0	.922	.902	22.43***	.000	97	.8412	5.81**	.015	9.5	13.36
3	lnturn2	lnturn9	1.055	.886	22.43***	.000	77	.8703	8.27***	.005	9.3	10.94
4	lnturn1	lnturn9	.884	.907	28.99***	.000	77	.9180	8.78***	.004	9.5	13.36

Table 7.9 Estimation Results- Employment Growth

Estimation	Dep. var	Indep. var	Const. a	Coef b	T Test b=0	p-value	N	R2	F Test b=1	p-value	s_t^*	St*
5	lnemp3	lnemp1	.320	.935	38.80***	.000	126	.9239	7.68***	.008	4.92	137
6	lnemp3	lnemp0	.446	.908	28.29***	.000	109	.8821	8.11***	.005	4.90	134
7	lnemp2	lnemp9	.495	.893	30.71***	.000	93	.9120	13.41***	.000	4.7	109
8	lnemp1	lnemp9	.365	.923	37.31***	.000	93	.9386	9.43***	.002	4.8	121

Table 7.10 Estimation Results- Labour Productivity Growth

Estimation	Dep. var	Indep. var	Const. a	Coef b	T Test b=0	p-value	N	R2	F Test b=1	p-value	s_t^*	St*
9	lnlbpr3	lnlbpr1	1.233	.693	11.75***	.000	111	.5587	26.9***	.000	4.02	55.7
10	lnlbpr3	lnlbpr0	1.562	.621	9.143***	.000	97	.4681	31.1***	.000	4.13	62.2
11	lnlbpr2	lnlbpr9	1.466	.655	9.995***	.000	77	.5712	27.5***	.000	4.26	70.8
12	lnlbpr1	lnlbpr9	1.045	.765	14.64***	.000	77	.7408	20.1***	.000	4.46	86.5

Notes: s_t^* is the natural logarithm and St* is the absolute value, where the growth process is stable (tends to an equilibrium value).

The results of regressions in the case of labor productivity growth are the ones that really validate the fact, that smaller high technology firms have higher growth rates compared to larger firms. In the case of labor productivity, the null hypothesis of H_0: β=1 is rejected for all regressions. The β < 1 and significant at 1% in all of the cases suggesting that, in the case of labor productivity small firms grow faster than large firms (see Table 7.10). In the case of turnover growth and employment growth, β approaches 1. Nevertheless, from the results in table 7.8, it is evident that the null hypothesis H_0: β=1 is rejected for all regressions for turnover growth. The β < 1 in all cases and is significant at 1% for three out of 4, for the remaining one it is significant at 5% suggesting that small firms have higher turnover growth than larger firms. Moreover, in the case of employment growth, evidence confirms that small firms have higher employment growth rates than larger firms. The b< 1 and the F statistic is significant at 1%, for all four estimations (see Table 7.9). It is to be noted that the long-run equilibrium employment sizes (St* of Table 7.9) implied by this version of the model are quite small, certainly much smaller than the sizes at which (the optimal size for innovation) Schumpeterian effect takes over.

The general conclusion is that, for the hi-tech sample, Gibrat’s Law of Proportionate Effect is refuted. The evidence suggests that small hi-tech firms have higher growth compared to largE firms. This is most convincing for labor productivity growth. The equilibrium state is reached for small firms (see last two columns of Tables 7.8, 7.9 & 7.10).

7.4 Conclusion

This chapter presents a detailed picture of the performance of hi-tech firms in the sample. Specifically, it highlights the influence of size on innovative performance, as well as economic performance. The main contributions are that broad set of measures and novel variables are used in the estimations. The specification and estimation methods used are more general, conclusive and robust, providing results which illuminate the key hypothesis.

Primarily, the non-linear relation between size and innovation are analysed by using robust estimation. The novelty here is that it is analysed by means of regression of a cubic function permitting the identification of inflection points and nonmonotonicity in the relation. It does so using a range of different measures of innovative performance that overarch the measurement of all stages, from R&D to patenting and new product introduction to new product sales. The results bring to light that in the case of Scottish hi-tech firms there exist a non-linear relation between firm size and innovation. Innovation is seen to increase with size until it reaches a maximum level, at 900 to 980 employee size. After this size the innovation is seen to fall as firm size increases until it reaches a minimum innovation at large firm size (3000 employees). Beyond this size, the innovation is seen to increase for the largest firms. Thus the overall results support the Shumpeterian hypothesis at very high scales only. At lower scales there is an optimal size, supporting small size advantage in innovation. This relationship is observed for the different innovation input and innovation output measures and also for the innovation volume, counts and intensities as well. The only exception is with respect to new product intensity, as this relationship does not hold for new product launched and for new product in pipeline intensity.

This chapter also contributes to the literature by testing the Gibrat’s law on hi-tech firms. It is tested by analysing the growth rate of turnover, employment and labor productivity to study the growth performance of firms, in relation to their size. The results are robust, and confirm that the Gibrat’s Law of Proportionate Effect is refuted for the hi-tech sample. It is the small firms that have higher growth rates, compared to large firms in hi-tech industries.

Chapter 8 Internationalisation of High Technology Firms

8.1 Introduction

This chapter examines the internationalisation of hi-tech firms in Scotland, and specifically, how firms try to achieve, improve and sustain competitiveness by pursuing international activities, i.e., global strategies, global networks, and exports. Focus here is on the performance of hi-tech firms in foreign markets, as well as the extent of international collaborations that these firms pursue in order to compete globally. The overriding importance of hi-tech firms, and their dominance in emerging industries of industrialized economies, makes it imperative to understand how they perform in international markets, with important implications for economic development and public policy.

Given the nature of hi-tech businesses, where being at the forefront in technology, leadership, unique products, and deep niche strategies are the norm, their operating environment is characterised by globalisation of competition, increasing complexity and variety of products, and escalating costs and risks, where customisation of innovation process, concentration on core competencies and internationalisation of R&D are pursued with vigour (Gassmann 2001), it is vital to expand internationally (Freel 2000a; Preece et al. 1999; Wagner 2001b; Lefebvre et al. 2001; Keeble et al 1998). Incorporating international strategies in firms has become a prerequisite in order to access the different sources of competitive advantage (Zahra et al 2000; Lu & Beamish 2001; Acs et al 1997).

Hi-tech products are ideally global. Hence, R&D has also to adopt an increasingly internationalized strategy (Gassmann & Reepmeyer 2005; Wakelin 1998). “Current R&D internationalisation has three distinguishing characteristics: it is taking place at a much faster pace; it is spreading to an increasing number of countries; and it involves a distinctive new trend where R&D extends beyond adapting technology to local conditions. Firms not only seek to exploit knowledge generated at home in other countries, but also to tap into worldwide centres of knowledge, implying genuinely international sourcing of knowledge” (OECD 2006). The key features of this research to be analysed in this chapter are:

- A detailed examination of the international orientation of firms in five hi-tech sectors in Scotland. This is examined in two parts. The first part (section 8.2) presents an overview of the international activities of firms, which is statistical in character. Section 8.2.1 deals with the international alliances and section 8.2.2 presents an overview of the export performance.

- In the process of assessing the internationalisation of these firms, the extent of their embeddedness in local networks and local market is revealed.
- In the second part of this chapter, an in-depth analysis of export performance is undertaken. Initially, a review of empirical work on the export performance of firms is carried out in section 8.3. This is followed by a preliminary analysis of: the size-export relation in firms (section 8.4); and the innovation-export relation (section 8.5). This part specifically tries to answer the following questions:

  a) Does firm size influence the export performance of hi-tech firms?, (Wagner 2001b;Chandler 1990; Lefebvre et al. 1998).

  b) Are innovators better performers, with respect to exports, compared to non-innovators? (Lefebvre et al. 1998; Roper & Love 2002).

  The purpose of this preliminary analysis is two-fold. Firstly, it presents the background information necessary for laying the ground for the multivariate analysis that is conducted in section 8.6, which is used to identify econometrically the determinants of export performance. Secondly, it brings to light, certain evidence with respect to export performance heterogeneity due to the influences of various types of innovation dimensions and size.
- The highlight of this chapter is a multivariate analyses using a Tobit model with sample selection, to determine the export performance in hi-tech firms, based on the theoretical perspective of the resource-based view of the firm. Specifically, the role of firm-specific factors, and the relative importance of innovation capabilities, as determinants of export performance, are analysed here (Lefbvre & Lefbvre 2002; Peteraf 1993; Grant 1991). This part builds on chapter 7, where hi-tech performance with respect to innovation and growth were analysed.

8.2 Extent of Internationalisation of High Technology Firms

'International' as defined here, means activities in the regions of Europe and outside Europe, and 'domestic' means regions of the UK, Scotland itself and its localities. It is increasingly seen that firms have exhibited a rapid increase in global networks, and a direct engagements in foreign locations, over the last decade (Hagedoorn 2002). The increasing similarity of technologies across sectors and the cross-fertilisation of technology between sectors, coupled with the increasing costs and risks associated with innovation, has often led firms to consider international R&D alliances as a first-best option. Through R&D co-operation and strategic alliances, leading international technological enterprises have created new solutions that allow for rapid and flexible networking of institutionally or regionally scattered centres of competence (OECD 2006).

The early stage internationalisation process of technology-based firms has attracted considerable attention (Keeble et al. 1998; Autio et al. 1997; McDougall & Oviatt 2000; Hollenstein 2005). There is much SME-oriented internationalisation literatures dealing with this (Lu & Beamish 2001; Preece et al. 1999; Wolf & Pett 2000; Acs et al. 1997). Such empirical work emphasises that in the pursuit of growth and higher return to resources, SMEs will sooner or later adopt internationalisation strategy to pursue new opportunities to leverage core competencies across a boarder range of markets (Zahra et al. 2000).

Many factors drive firms to pursue international strategy. Innovations are the result of the interplay between the firm and its environment (Schmookler 1966). It is crucial to remain at the forefront of their narrow technological niche and to capitalise on the innovations that may result from the interplay with different environments. Firms operating in various environments are more likely to generate a variety of innovations related to their core technology than firms operating only domestically. The desire to gain first-mover advantages motivates small firms in emerging industries to invest abroad. The firms must also pre-empt, as far as possible, the emergence of competitors within their narrow area of expertise (Kohn 1997). Gaining such advantages abroad is particularly important for small, highly focussed firms. The entry barriers limiting international expansion are higher for small technology firms, making their international business ventures risky (Fujita 1995). Firms circumvent these barriers by using direct and intermediated ways of international expansion, like using existing multinationals as international conduits for international expansion (Acs et al. 1997).

The role of entrepreneurs in early-stage internationalisation in firms is evident from empirical work, (McDougall & Oviatt 2000; McDougall 1989). It is seen that traditional theories of business internationalisation such as monopolistic advantage theory, product cycle theory, stage theory, oligopolistic reaction theory, and internalisation theory, fail adequately to explain this phenomenon. Instead, it is explained by, highly qualified entrepreneurs with exceptional awareness of high-return international market opportunities.

The entrepreneur's competencies derived from previous employment, technological expertise, and existing international networking, leads to internationalisation in small firms compared to domestically focussed entrepreneurs (Coviello & Munro 1995).

Much empirical work in recent years deals with the relevance of various constraints that SMEs have confronted on expanding internationally, such as lack of finance, insufficient management capacity (Acs et al. 1997; Fujita 1995) and also the firm's choice of the ownership mode of entering foreign markets (Hollenstein 2005). Moreover, a U.N. Report (1993) points out that among firms with foreign operations, SMEs tend to have partially owned foreign affiliates while large firms have fully-owned affiliates. In the report, it is found that only 47% of smaller firm's foreign affiliates are wholly owned, compared to 53% for large firms. Additionally, 26% of SME's foreign expansion is known to take the form of joint ventures, versus 17% for large firms. Moreover, it is seen that international expansions by smaller firms are more likely to fail, (Newbound et al. 1978).

Hollenstein (2005) investigated the determinants of international activities in the Swiss economy. The findings are that, the larger a firm's stock of specific assets and capabilities, the higher the probability of internationalising all business functions i.e. exports, distributive activities, production and R&D. Innovation-related capabilities, human capital and firm-specific assets in marketing, organisation and finance turned out to be the most important drivers of internationalisation irrespective of firm size and type of strategy. The large firms more often tend to internationalise their activities than smaller companies. However, size matters only up to a certain threshold (200 employees), and is merely relevant in the case of strategies involving a direct presence at foreign locations. At the small scale, in terms of the availability of firm-specific assets, the firms are increasingly serving foreign markets without directly being engaged at foreign locations.

The SMEs more often choose contractual rather than equity-based forms of internationalisation. Lu & Beamish (2001) looks at the performance implications of four international diversification strategies of SMEs: the exporting, the international alliances, the FDI and the joint effects of exporting and FDI. They find that a key strategy for overcoming the resource limitations that frequently constrain an SME's internationalisation expansion is the use of alliance with firms that have local knowledge. Turning now to the evidence of this thesis, the data here suggests that the hi-tech firms are truly international, with a strong focus on international strategies. The firms in the sample are highly export oriented in terms of high export participation rate, high export intensity as well as greater market extent. International strategic alliances, namely vertical alliances (suppliers, customers), horizontal partnerships with universities, trade and government bodies, informal alliances with competitors and others (.g. on information etc.) are also evident. The distribution of hi-tech purchases shows that 62.54% of purchases are from overseas markets. The highest percent of purchases are from outside Europe (37.18%) and 25.36% are from Europe. Additionally, more than 50% of the firms are sourcing from overseas and about 4% purchases from foreign markets alone.

8.2.1 International Networks

On examining the hi-tech networks in detail, the evidence confirms that there is a high degree of internationalisation, as the data displays a global orientation in collaborations of hi-tech firms. Table 8.1 presents the proportion of firms engaging in international as well as domestic alliances. A very high proportion of firms (83.44%) have international alliance. 77% have collaborations outside Europe, and 70% have alliance in Europe. χ^2 test was performed to see whether the proportion of firms that have collaborative alliance is significantly different from those without alliance. It confirms that the proportion of firms with international collaborative alliance is significantly greater (at 1%, df=1, χ^2 =67.556). In particular, it is significantly greater for Europe (at 1%, df=1, χ^2=23.05), as well as outside Europe (at 1%, df=1, χ^2=45.62). This emphasises the importance that hi-tech firms attach to global networks.

Table 8.1 Percentage of Firms with Alliances

International (outside UK)	*Outside Europe*	*Europe*	*UK*	*Scotland*	*Local*
83.44	77.48	69.54	93.38	88.08	62.91

8.2.1.1 International-networked versus Domestic-networked Firms

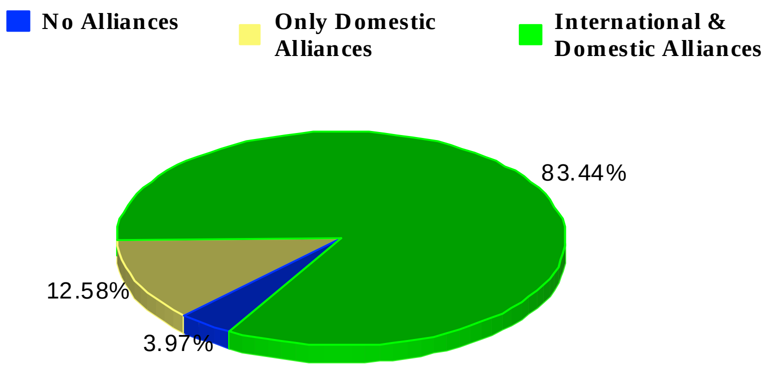
It is important to understand how different is the nature of collaborations of internationally focussed firms, in comparison to firms with no international collaborations? Figure 8.1 presents the percentage of firms in three categories. The first category consist of firms with both international and domestic alliances (83.44%), the second constitutes firms with domestic alliances alone (12.5%), and third are firms with no alliances. The network pattern of the first two categories is investigated in detail. Firms focussing on international network strategy, pursue far more intense alliances compared to the other. These firms collaborate more, and have a greater number of alliances with their collaborators compared to firms with domestic alliances only. Their share in the total number of alliances with all collaborators is 94%, as compared to 6% for firms with the latter, with the average number of alliances being 33.80 and 13.79, respectively. An independent samples test confirms that internationally networked firms have significantly (at 1%, t=2.744, df=149) greater mean compared to the other. It is important to understand why internationally networked firms collaborate more, compared to domestically networked firms. Prima facie, this difference in the number of alliances of these two categories could be due to the:

i) difference in firm size, (Almeida & Kogut 1997; Love & Roper 1999)

ii) different collaborators (Zahra et al. 2000; Baum et al. 2000; Belderbos et al. 2004)

iii) difference in firm's innovation capacity (Kaufmann & Tödtling 2001; Chesbrough 2003a)

Figure 8.1 External Alliances- % of firms



i) Size Difference

The influence of firm size may be the reason for the different network pattern of the two categorise, (Almeida & Kogut 1997). The mean number of alliances by firms in the two categories for different sizes is presented in Table 8.2. It is found that, across all the size categories, internationally networked firms have greater alliances compared to firms with domestic alliances alone. It is significantly greater for the firms in the 'small' category at 10% (by Independent Sample Test, t=1.874, df=51). Since there was only one category for large size, an independent sample test could not be performed (see Table 8.2). It suggests that the increased collaboration by internationally focussed firms (1st category), is seen across all size categories (Hollenstein 2005).

Table 8.2 Mean alliances by Size & Category

Category		Micro	Small	Medium	Large	Total
Firms with international & domestic alliances	Mean No.	28.43 63	29.83 47	42.5 8	90.75 8	33.80 126
Firms with domestic alliances only	Mean No.	14.55 11	11.17 6	17.5 2	- 0	13.79 19

ii) Different type of Collaborators

The influence of different collaborator-type on the network patterns of the two categories, are analysed by looking at alliances with suppliers, customers, competitors, research organisations, government bodies, trade organisations and finance bodies (Zahra & George 2002; Baum et al. 2000; Belderbos et al. 2004; Hagedoorn & Schakenraad 1994). The differentiation of the total alliances into 7 different collaborators reveals that, firms in the first category collaborate more, irrespective of the collaborator type, compared to firms with just domestic alliances.

Table 8.3 Independent Samples Test- Collaborator Type

Collaborator		Levene's Test for Equality of Variances		t-test for Equality of Means			
		F	Sig.	t	df	Sig. 2-tailed	Mean Difference
Supplier	Equal variances assumed	3.401	.067	2.081	149	.039	7.227
	Equal variances not assumed			4.138	144.2	.000	7.227
Customer	Equal variances assumed	3.060	.082	2.155	149	.033	6.270
	Equal variances not assumed			4.299	144.9	.000	6.270
Competitors	Equal variances assumed	2.130	.147	1.868	149	.064	2.550
	Equal variances not assumed			3.976	146.1	.000	2.550
Research	Equal variances assumed	.806	.371	2.961	149	.004	2.086
	Equal variances not assumed			4.646	73.36	.000	2.086
Government	Equal variances assumed	.977	.325	1.598	149	.112	1.795
	Equal variances not assumed			3.230	147.2	.002	1.795
Trade	Equal variances assumed	.527	.469	1.135	149	.258	1.285
	Equal variances not assumed			2.141	128.1	.034	1.285
Finance	Equal variances assumed	2.261	.135	1.526	149	.129	2.107
	Equal variances not assumed			3.295	142.5	.001	2.107

But the independent sample test (see Table 8.3) confirms that the mean number of research alliances (significant at 1%), customer alliances (significant at 5%), supplier alliances (significant at 5%) and competitor alliances (significant at 10%) are higher. There is not much difference in the number of government, trade and finance alliances that international focused firms have, compared to the second category. The evidence has confirmed that the greater alliances by internationally networked hi-tech firms are mainly a result of greater research, supplier, customer and competitor alliances (Tether 2002; Monjon & Waelbroeck 2003; Romijn & Albu 2002).

iii) Different Innovation Capacity

The increased collaboration reported by internationally collaborating firms could also be due to greater innovation capacity (Tether 2002; Monjon & Waelbroeck 2003). Research networks tend to be most important where the innovation is relatively radical in orientation (Fritsch 2001). The collaborations of the two categories are differentiated here by four innovation categories as shown in Table 8.4. It is seen that innovation output certainly statistically explains the increased collaborations by internationally focussed firms. The independent samples test is significant only for the first innovation category, (firms with innovation output). In fact, internationally networked firms without innovation output, have less collaborations compared to domestically networked firms.

Table 8.4 Independent Samples Test Innovation

Innovation Category		Levene's Test for Equality of Variances		t-test for Equality of Means			
		F	Sig.	t	df	Sig. 2-tailed	Mean Difference
Firms with innovation output	Equal variances assumed	2.82	.095	2.190	137	.030	22.79
	Equal variances not assumed			4.912	100.8	.000	22.79
Firms without innovation output	Equal variances assumed	901.3	.000	-1.109	4	.329	-12.50
	Equal variances not assumed			-1.664	3.00	.195	-12.50
Firms with innovation input	Equal variances assumed	1.53	.218	1.547	117	.125	19.69
	Equal variances not assumed			3.587	54.61	.001	19.69
Firms without innovation input	Equal variances assumed	.36	.556	1.486	24	.150	18.39
	Equal variances not assumed			2.088	23.17	.048	18.39

Thus on analysing the collaborations of hi-tech firms, it can be concluded that internationally focussed firms pursue greater networks compared to domestically networked firms. These firms network more as a result of their innovation activities, in particular involving product innovation and patenting. Also, it can be inferred from the data that, the more alliances that firms pursue through international collaborations, the greater do they network with research organisations, suppliers, customers and competitors. Further, both small, as well as large internationally focussed firms pursue external networks.

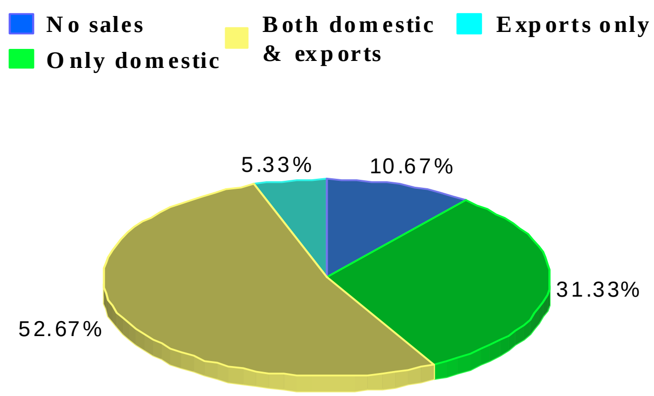
8.2.2 An Overview of the Export Performance of the Hi-tech Sample

Exports are defined here as all sales to foreign markets, ie., outside UK. Here, export performance is evaluated by using three export measures.

- Firstly, participation in exports is examined by looking at the percent of firms involved in exporting.
- Secondly, the export intensity is measured as the firm's export share, as a proportion of total sales.
- The third focus is on the market extent, measured as the proportion of total sales in foreign markets, as compared to domestic markets.

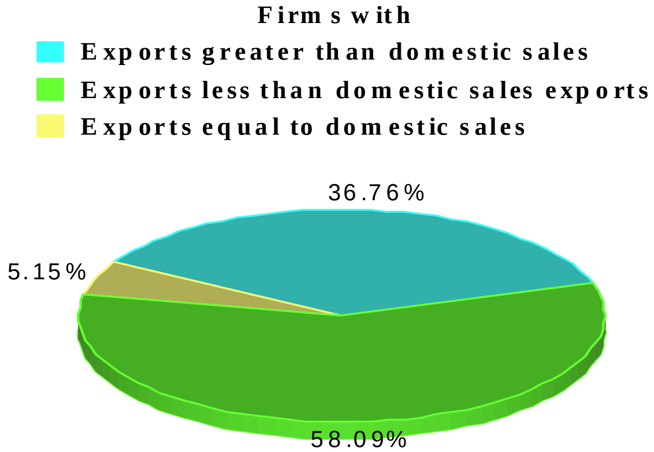
With these definitions in mind, these results follow. Firstly, the majority of the firms are exporters (58%). For 5.33% of the firms, all their sales are attributed to export sales. Figure 8.2 presents the proportion of firms, with both exports and domestic sales, only exports, only domestic, and development firms.

Figure 8.2 Export Activity of Firms



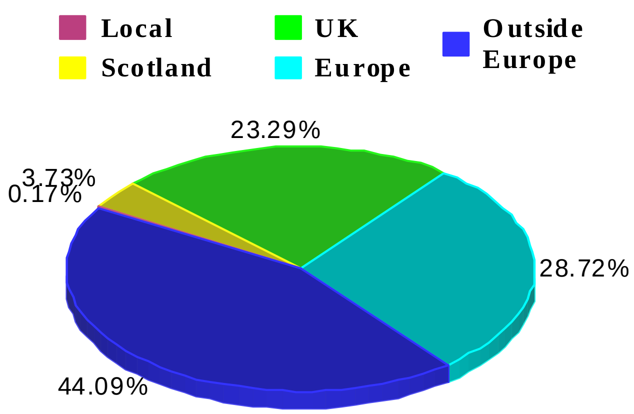
Secondly, the exports account for about three quarters of the hi-tech firm's total sales, (72.81%), revealing that the firms in the hi-tech sector are export intensive. Moreover, over 36% of the firms had greater export sales compared to domestic sales, 5.15% of the firms had equal export sales and domestic sales, as is evident in Figure 8.3.

Figure 8.3 Export versus Domestic Sales



Thirdly, the market extent of the total sales reveals that the largest proportion of the total sales are in the markets outside Europe (44.09%), followed by sales in Europe (28.72%). Figure 8.4 displays the sales distribution in the five different markets: local, Scotland, UK, Europe and outside Europe. These figures suggest that hi-tech firms are export intensive, with respect to greater participation, export sales, and distant export markets.

Figure 8.4 Sales Distribution in the Five Markets



8.3 Review of Empirical Evidence on Firm-level Export Performance

The literature on firm-level determinants of export performance is extremely rich (Chetty & Hamilton 1996), and covers a wide spectrum of issues, such as the relative importance of firm's demographics (Wagner 2001b, 1995a) and the relative impact of the beliefs, attitudes and perceptions of top management (Bijmolt & Zmart 1994). R&D, level of automation, degree of modernization of equipment/machinery, technical knowledge intensity, unique know-how and quality norms, are all seen to influence exports.

Firstly, looking at the empirical relevance of size on exports, it is found that although the traditional assumption, that in order "to compete globally you have to be big" (Chandler 1990) holds in several studies, a significant number of researchers have found no relationship, or a negative relationship, between size and exports (Calof 1993). These ambivalent results are partially explained by the non-linear nature of this relationship (Lefebvre et al. 1998). Furthermore, it is found that above a certain threshold size no longer plays a significant role (Hollenstein 2005). Evidence from Australia, Denmark, Italy, Japan and Spain supports the view that size is of considerable importance during the first stages of internationalisation, but is not a significant factor afterwards (OECD 1997). Export-size relation is examined in sections 8.4 and 8.6.

Specifically, in the hi-tech context competition is increasingly technology-based, hence it is seen that innovation capabilities play a major role in determining a firm's propensity to export (Freel 2000a; Hollenstein 2005; Roper & Love 2002). Theoretically, there exists a clear positive relationship between value added, uniqueness of product and export propensity. Wynarczyk & Thwaites (1997) find evidence of high involvement and growth of exports in the innovative small firm sector. Moore (1995) finds a positive relationship between innovative activity (new products) and export performance. Lefebvre et al. (2001), demonstrates the predominance of technological capabilities over the commercial capabilities, as determinants of both the firms' export performance as well as its propensity to export, in SMEs from high-knowledge industries. At the same time, in low and medium knowledge industries, commercial capabilities are more salient.

Export and innovation are likely to be inter-related. In general, innovative firms may seek to exploit overseas markets, suggesting that the causality runs from innovation to exports. Empirical studies have shown that this appears to be the case (Lefebvre et al. 1998), although it suggests a need to carefully control for both the nature of innovation, and the type and destination of exports. Small exporters are able to compete on foreign markets because of their technological capabilities, (Lefebvre et al. 2001; Khon 1997).

Among technological capabilities, in-house R&D not only generates innovations but also allows firms to better assimilate external technological knowledge. This is one of the prime factors influencing export performance, (Ong & Pearson 1984). Moreover, SME exporters conduct more R&D (Baldwin et al. 1994) and produce more patents (Moini 1995). Additionally, the number of engineers, scientists, and technicians reflects a firm's stock of technological knowledge and technological knowledge intensity is strongly related to its export performance (Lefebvre et al. 1996, 2001).

However, the link is less easily established in other studies. Cesaratto & Stirati (1996), for instance, note only a marginal difference between share of exports on sales in small innovators and non-innovators (24% and 21%), although they do note a significantly higher rate of growth in exporting in innovators (9.27% as opposed to 4.25% in non-innovators). Lefebvre et al. (1998), was unable to establish any relationship between R&D and export performance, and Sriram et al. (1989) observed a negative relationship. Yet, despite the frequently contradictory results, the bulk of the evidence points to a greater likelihood to export and (to export more) on the part of the most innovative firms (Lefebvre & Lefebvre 2002; Freel 2000a; Wynarczyk & Thwaites 1997). Sections 8.5 and 8.6, investigates the correlation between exports and innovation in firms on a number of innovation dimensions.

Other firm characteristics such as age, manufacturing status, unionisation etc. are seen to influence exports. On the one hand, more mature firms having accumulated considerable knowledge stocks, and with strong core capabilities, are better able to penetrate foreign markets. On the other hand, core capabilities can become core rigidities or competence traps (Leonard-Barton 1992) and younger firms are seen to be more proactive, flexible and aggressive. Larger, more mature manufacturers rely on domestic SMEs to provide them with components and subsystems that are inputs to their own products. It is therefore seen that contractors realize more direct export sales than subcontractors. Evidence show that the presence of trade union affiliation negatively influences exports (Greenhalgh et al. 1994). Other factors like adoption of technologies and technical/quality standards are seen to influence the export. Adoption of advanced manufacturing technologies has long been recognized as a key factor in the competitiveness of manufacturing firms. Benefits from automation increase both in scope and intensity, and employee’s skills are enhanced with increased technological penetration (Lefebvre et al. 1996). In fact, the myth of deskilling following the adoption of new technologies has been strongly contested (Lefebvre et al. 1996). International norms such as ISO 9000 are in most cases a prerequisite for export activities (Chetty & Hamilton 1996). Lefbvre et al. (2001) did not find any impact of quality norms on the export performance.

Empirical research has evaluated the relative contributions of a broader range of commercial capabilities to export performance, namely diversification, trademarks and/or proprietary products, networking other firms, distribution access, manufacturing agents and import activities. Diversification strategy, like operating in a number of industries, range of products and diversity of product lines have a positive influence on exports, as the knowledge and experiences acquired in one industry can be transferred to others, with respect to commercial and competitive watch practices, which are highly related to export success (Christensen 1991; Cafferata & Mensi 1995). In contrast, diversification does not contribute positively to SME’s export performance, in fact it had a negative impact (Lefbvre et al. 2001). This is in line with the recent trend to reduce diversification and focus on core businesses (Markides 1995), at least in the case of large firms.

Competitive advantages drawn from a unique product (Haar & Ortiz-Buonafina 1995) or product specificity (Julien et al. 1994) are positively linked to export performance. Market intelligence and marketing capabilities (Haar & Ortiz-Buonafina 1995) are shown to be prerequisites to export entry and expansion. The presence of trademarks and proprietary products are considered an asset for firms operating on foreign markets. The first-hand knowledge of international activities is also seen to influence the export performance of SMEs positively. Import activities allow SMEs to experience cross-border activities with minimal risks. Finally, networking also seems to enhance export performance (Julien et al. 1994; Chetty & Hamilton 1996).

8.4 Exports and Size of Firms

Here the export performance of firms in different size class is explored, by examining the export participation, export intensity and the market extent. This preliminary analysis reveals certain interesting results. The export measures are all significantly greater for the large firms compared to smaller firms. The ANOVA test for difference in the export measures across firm size is not rejected, as the F-statistic is significant at 1% for the export intensity (F= 5.462, df=3), and for the share of exports in Europe markets (F=26, df=3), and outside Europe (F= 33, df=3). It is significant at 5% for the percentage of exporting firms (F= 3.3, df=3). Table 8.5 presents the correlation between export and size measures.

Table 8.5 Correlation between Export Measures and Firm Size

Kendall's tau		Employment	Turnover
Percentage of Exporting Firms	Correlation Coefficient Sig. (2-tailed) N	.184** .007 151	.334** .000 150
Exports Sales Intensity	Correlation Coefficient Sig. (2-tailed) N	.237** .000 134	.236** .000 134
Local sales as a proportion of total sales	Correlation Coefficient Sig. (2-tailed) N	-.201** .003 136	-.194** .004 136
Scotland sales as a proportion of total sales	Correlation Coefficient Sig. (2-tailed) N	-.157* .012 136	-.131* .034 136
UK sales as a proportion of total sales	Correlation Coefficient Sig. (2-tailed) N	.040 .508 136	.068 .259 136
Europe sales as a proportion of total sales	Correlation Coefficient Sig. (2-tailed) N	.156* .014 136	.162** .010 136
Outside Europe sales as a proportion of total sales	Correlation Coefficient Sig. (2-tailed) N	.238** .000 136	.259** .000 136

** significance at 1%, * significance at 5%,

i) Export Participation & Size

The percentage of firms involved in exporting is seen to increase with the size of firms. There is a positive and significant correlation with size. However, it is weak for employment and slightly strong for turnover. Table 8.6 displays the percentage of firms in each size category according to their export status.

Table 8.6 Firms undertaking Export across Firm Size

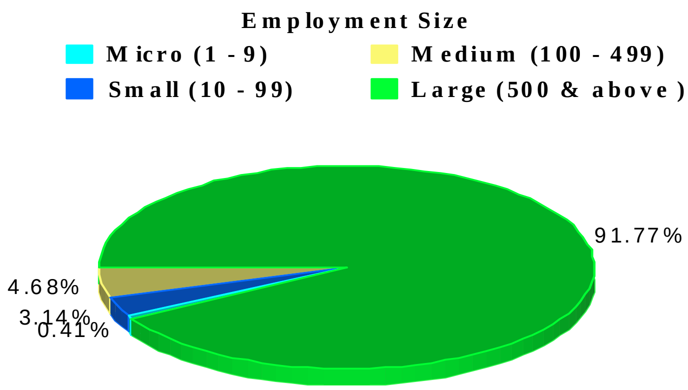
	Micro	Small	Medium	Large
No Sales	14.3%	9.3%	-	-
Domestic Sales Only	36.4%	29.6%	30%	-
Exports Only	1.3%	9.3%	10%	11.1%
Domestic & Exports	48.1%	51.9%	60%	88.9%
	100	100	100	100

Though a majority of small and medium-sized firms and all of the large firms do exports, half of the micro firms do not. This is because 14.3% of the micro firms are still in a development phase, and are yet to launch any products, and 36.4% are involved only in domestic sales.

ii) Export Intensity & Size

The large firms contribute mostly to the exports (see Figure 8.5). 91.77% of the exports in the sample are by the large firms, and the SME share is only 8.23%, indicating that size has a positive effect on the export volume. With respect to the export intensity, it has a weak, positive and significant correlation with turnover, as well as employees, (see Table 8.5).

Figure 8.5 Export Sales distribution by Size



iii) Market Extent & Size

The sales of hi-tech firms increase with the size of the firm for the regions Europe & outside Europe. There is significant positive correlation between sales in Europe and firm size, (Kendall's tau_b significant at 5%). In the case of sales outside Europe it is significant at 1%, (Kendall's tau_b correlation coefficient =.24 for employment, and .26 for turnover). Where as it decreases with size for sales in Scotland and Local, (domestic market). There is weak positive correlation between sales in UK and size, (not significant). There is significant negative correlation in the case of local sales and Scotland sales (see Table 8.5).

Thus it is seen that, larger firms exhibit greater export performance than smaller firms. All three export measures are greater for large firms compared to small hi-tech firms. It is also evident that export sales do not increase with scale of domestic sale. Instead there is a negative correlation between export intensity and domestic sale intensity (Kendall’s tau -

.274, significant at 1%). Nevertheless, the analysis here is based on simple correlation between firm size and exports, and mean comparisons. Many other relevant variables may be better able to explain the underlying export performance.

8.5 Innovation as a determinant of Export Performance

Here a statistical analysis of the impact of innovativeness of hi-tech firms on their export performance is undertaken, and tries to answer the questions:

- **i)** Are innovators more likely to export?
- **ii)** Are innovators likely to export more compared to non-innovators?
- **iii)** Are innovators exporting to more distant markets compared to non-innovators?

In this thesis, various measures are used to distinguish innovators from non-innovators. Product innovators are firms involved in new product development and/or having new product sales in the past five years. Innovators with respect to patent are firms with least one patent granted or filed in the last five years. Innovators in terms of innovation input are firms with in-house innovation expenditures and/or R&D department.

i) Propensity to Export

The evidence suggests that innovators have greater export propensity. In particular, firms with innovation output have a greater propensity to export. Table 8.7 presents the correlations (Kendall's tau) between export and various innovation dimensions. The correlation is significant and positive for firms with new product sales, patents (both significant at 1%) and product innovation (significant at 5%). The Mann-Whitney test (see Table 8.8) confirms that innovators (on measures like product innovation, new product sales & patent) have greater mean compared to non-innovators. It is significant for product innovation. This indicates that innovative firms are able to enter export markets competing on technology, speed-to-market, novel products at low cost etc (Freel 2000a; Lefebvre et al. 1998; Moini 1995).

ii) Export Intensity

Innovators report higher export intensity (Wynarczyk & Thwaites 1997; Lefebvre et al. 1998; Khon 1997). There is a significant, strong positive correlation for firms with patents and R&D department (at 1%), and a weak positive correlation for firms having innovation expenditures (at 10%), (see Table 8.7). The Mann-Whitney test confirms that innovators have greater mean compared to non-innovators, for all innovation categories except for firms with new product sales. It is significant at 1% for firms with patents and R&D department, indicating that continuous, in-house R&D significantly increases export intensity (Ong & Pearson 1984; Baldwin et al. 1994).

Table 8.7 Correlation between Export Performance and Innovators

Kendall's tau		Innovating Firms With: New product	New product sales	Patents	Innovation Expenditure	R&D Department
% of exporting firms	Correlation Coefficient	.194**	.308***	.247***	.077	.117
	Sig. (2-tailed)	.018	.000	.002	.347	.153
	N	151	151	151	151	151
Export Intensity	Correlation Coefficient	.037	.058	.420***	.134*	.331***
	Sig. (2-tailed)	.621	.440	.000	.074	.000
	N	134	134	134	134	134
Outside Europe	Correlation Coefficient	.065	.193***	.320***	.099	.238***
	Sig. (2-tailed)	.378	.009	.000	.180	.001
	N	150	150	150	150	150
Europe	Correlation Coefficient	.133*	.252***	.255***	.138*	.158**
	Sig. (2-tailed)	.067	.001	.000	.056	.030
	N	150	150	150	150	150
UK	Correlation Coefficient	-.035	.260***	-.018	.028	-.049
	Sig. (2-tailed)	.617	.000	.795	.686	.477
	N	150	150	150	150	150
Scotland	Correlation Coefficient	.088	.285***	-.214***	-.008	-.189***
	Sig. (2-tailed)	.219	.000	.003	.915	.008
	N	150	150	150	150	150
Local	Correlation Coefficient	-.018	.082	-.114	-.074	-.135*
	Sig. (2-tailed)	.814	.289	.140	.336	.080
	N	150	150	150	150	150

***Correlation significant at the 0.01 level (2-tailed) **Correlation significant at the 0.05 level (2-tailed)
*Correlation significant at the 0.1 level (2-tailed)

Table 8.8 Mann-Whitney Test for the Probability to Export

	Innovators		Non-Innovators		
	Number	Mean	Number	Mean	Z
New Product	132	.8485	8	.6250	-1.651*
New Product Sale	98	.9082	28	5.714	-4.4***
Patent	41	.8537	99	.8283	-.367
Expenditure	115	.8348	25	.8400	-.064
R&D department	57	.7895	81	.8642	-1.156

Table 8.9 **Mann-Whitney Test for Export Intensity**

	Innovators		Non-Innovators		
	Number	Mean	Number	Mean	Z
New Product	101	.7369	5	.6200	-.388
New Product Sale	89	.7179	10	.8700	-1.620
Patent	32	.9344	74	.6436	-4.242***
Expenditure	88	.7509	18	.6361	-.915
R&D department	38	.8695	66	.6544	-3.237***

iii) Market Extent

It is evident from the correlation test presented in Table 8.7, that patenting firms, firms with new product sales and firms doing continuous R&D have a greater market extent. Correlation is significant, strong and positive for sales outside Europe and in Europe. Firms with patents and R&D department, has a significant, strong, negative correlation for domestic sales. Innovators are seen to have greater export extent and the non-innovators have greater domestic sales.

8.5.1 Export Performance of Innovating Firms

The export performance of hi-tech firms who are innovators according to the measures explained above, are explored here. Figures 8.6 to 8.8 present evidence on the export share in relation to their level of innovation.

Figure 8.6

Export & Product Innovation

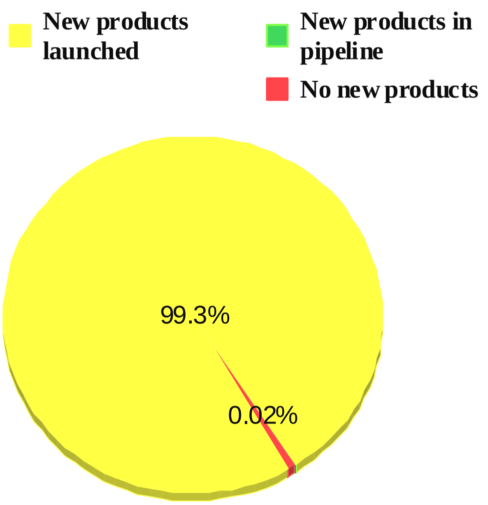


Figure 8.7

Export & Patent Innovation

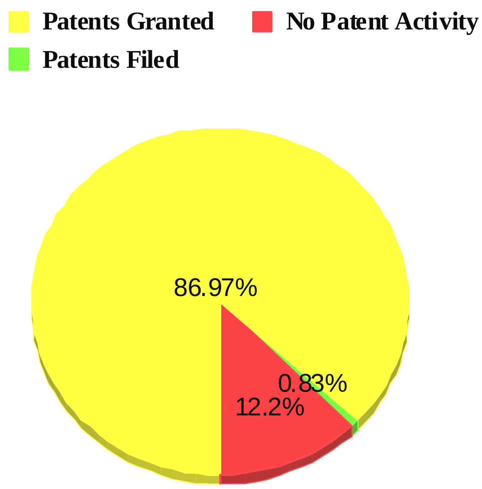
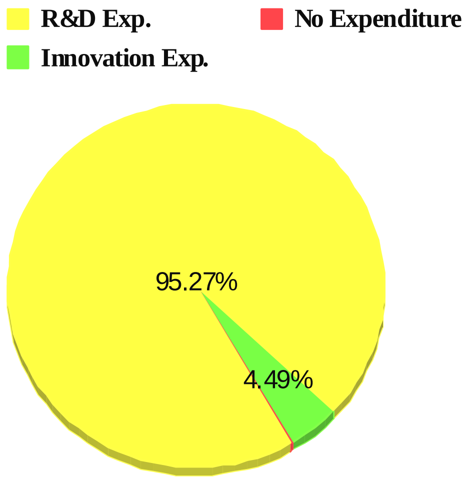


Figure 8.8 Export & Innovation Expenditures



Of the innovative firms, a higher level of innovation activity is seen to enhance greater export sales. This was true for patent, product innovation and in the case of expenditure as well. Firms with new products launched, accounted for 99% of the exports and firms with patent granted accounted for about 87%. Firms with R&D expenditures accounted for 95% of the exports, firms with innovation sales accounted for 98%. Firms with R&D department have greater exports.

Correlations between the different innovation measures, and export measures are presented in Table 8.10. There is a significant, strong positive correlation (at 1%) between export measures and all innovation measures using Kendall's tau_b indicating that a higher innovation level enhances greater export intensities in hi-tech firms.

Table 8.10 Correlation between Export Performance and Innovation Extent

		New Products	New Product Sales	Patents	Innovation Expenditure	R&D Staff
Propensity to Export	Correlation Coefficient	.214***	.300***	.235***	.225***	.152**
	Sig. (2-tailed)	.002	.000	.002	.001	.028
	N	151	150	151	151	149
Export Intensity	Correlation Coefficient	.135**	.186***	.410***	.315***	.217***
	Sig. (2-tailed)	.030	.003	.000	.000	.001
	N	134	134	134	134	133
Outside Europe	Correlation Coefficient	.236***	.357***	.326***	.308***	.332***
	Sig. (2-tailed)	.000	.000	.000	.000	.000
	N	150	149	150	150	148
Europe	Correlation Coefficient	.254***	.393***	.258***	.290***	.259***
	Sig. (2-tailed)	.000	.000	.000	.000	.000
	N	150	149	150	150	148

*** Correlation significant at the 0.01 level (2-tailed), ** Correlation significant at the 0.1 level (2-tailed).

8.6 Estimation of the Determinants of Export Performance

In this section, a multivariate analysis is undertaken of the contribution and relative importance of the determinants of export performance, in hi-tech firms. Tobit estimation with correction for sample selection was the preferred method as it allows one to assess respectively:

i) the contribution of the independent variables to the firm's propensity to export.

ii) the explanatory power of these independent variables in determining the firm's export performance.

The procedure for estimating this model follows the standard set of steps for selectivity models as given below. The model is specified as:

Propensity to Export

$$g_i = \begin{cases} 1 & \text{if } g_i^* = x_{1i}b_1 + u_{1i} > 0 \quad \text{(firms with exports)} \\ 0 & \text{if } g_i^* = x_{1i}b_1 + u_{1i} \leq 0 \quad \text{(firms without exports)} \end{cases} \qquad 8.1$$

Export Intensity

$$k_i = x_{2i}b_2 + u_{2i}, \quad \text{if } g_i = 1 \qquad 8.2$$

where, g_i^* is the latent export decision variable dependent on x_1, a vector of variables that explain the firm's export decision. g_i is a binary variable, the observable counterpart of g_i^* which is equal to 1 if the firm is involved in exports, and zero if it is not. k_i describe export intensity (exports as a proportion of total sales), and is dependent on x_{2i}, a vectors of various variables explaining the export performance of firms. The same set of variables is used as x_{1i} and x_{2i}. The b's are the unknown parameter vectors. u_{1i} and u_{2i} are i.i.d. drawings from a normal distribution with zero mean.

In the first step, equation (8.1) is estimated for the full sample, using a probit model to determine the factors that explains the export decision and their impact on the probability of exports. 42% of the firms in the sample have no exports. This would mean that there could be a sample selection bias if only the exporting firms were selected for the second equation. The estimates of the probit equation are used to construct an Inverse Mills Ratio (IMR), which is an additional variable in equation 8.2, to correct for sample selection bias.

The explanatory variables in this model are selected in the light of the empirical literature discussed in section 8.3 and also the preliminary analysis done in sections 8.4 and 8.5 on the size-export and innovation-export respectively. It is presented in Table 8.11.

Table 8.11 Descriptions of the Variables

Firm's General Characteristics:

1. Size - Number of employees
2. Size^2 - Square of Size
3. Age - Ranges from one year to at least five years
4. Intentp - International Entreprenure, dummy variable, 1= if firms' entreprenure are from overseas

Innovation-related Indicators:

5. Innexp - Innovation Expenditure, dummy variable, 1= if firm incur in-house innovation expenditures
6. Innsale - New Product Sales, dummy variable, 1= firm with sales from new products & services in the last 5 years
6. Patent - dummy variable, 1= firm with patents granted or filed in last 5 years

Networking Intensity:

8. Resnet - Research Network Intensity, number of alliance with research organisations per employee
9. Govnet - Government Network Intensity, number of alliance with government organisations per employee
10. Cusnet - Customer Network Intensity, number of customers alliances per employee

Organisational Strategy: F*irms' importance ratings on a 5-point Likert scale on:*

11. Prdstg - Product Strategy, like improved products, extended product range
12. Mktstg - Market strategy, increased or retained market share strategy

Obstacles : *Firm's importance ratings on a 5-point Likert scale on :-*

13. Ecobst - Economic Obstacles, economic factors hampering innovation

The variables are employment size, square of employment size, age, network intensities with customer, research and government organisations, and the significance of economic obstacles to innovation in firms. Three dummy variables are included to denote innovation. The first two are: firms involved in patenting; and firms with innovation expenditures. As the commercial success of innovation in the past will have an effect on exports, as well as on the decision to export, the dummy variable for sales from new products and services launched in the last five years is also included.

8.6.1 Estimation Results and Discussion

The estimation results of the two equations in the tobit model are presented in Table 8.12.

Table 8.12 Estimation Results - Export Performance

Dependent Variable	***Probit Part* Propensity to Export**			***Tobit Part* Export Intensity**		
	Coeff.	***t***	***pvalue***	***Coeff.***	***t***	***pvalue***
Age	0.059	0.544	.586	0.003	0.105	.916
Size	-0.014	-0.706	.480	0.38e-03**	2.110	.034
$Size^2$	0.30e-03	1.444	.148	-0.73e-07*	-1.87	.062
Intentp	-0.639	-1.301	.193	0.219*	1.877	.060
Ecobst	0. 053	0.470	.638	0.059**	1.983	.047
Innovation						
Patents	1.037***	2.653	.008	0.537***	6.085	.000
Innsales	1.505***	3.395	.000	0.789***	4.998	.000
Innexp	-0.294	-0.695	.486	0.172	1.443	.148
Strategies						
Prdstg	0.009	0.077	.938	-0.079**	-2.36 6	.018
Mktstg	0.032	0.294	.768	0.051*	1.837	.066
Network Intensity						
Cusnet	-0.045	-0.601	.547	-0.057	-1.409	.158
Resnet	-0.173	-0.731	.464	-0.023	-0.248	.803
Govnet	0.417	1.466	.142	0.171**	2.117	.034
Constant	-1.739**	-1.978	.047	-1.089***	-3.756	.000
Inverse Mills ratio				0.705***	8.252	.000
Chi-squared	39.1***					
R-squared	.224			.612		
Observations	118			118		
F Test	2.32, df = 104, P value .009			11.61, df =103, P value= .000		

Beginning with the first equation, the probit estimate itself has a highly significant χ^2 (39.113, sig at 1%), and the ability of the probit estimates to distinguish between the two groups is very high, correctly predicting 49 out 50 of the firms without exports, and 69 out of 68 the firms with exports. It is seen that the *inverse mills ratio* that corrects for selectivity is significant at 1% indicating that sample selectivity is an issue here and that it is important to take into account selection bias by using probit step. The propensity to export significantly increases with a firm's innovation capabilities. Patenting firms and firms with innovation sales have a significantly greater propensity to export. It is evident here that, the innovation output variables show a significant positive impact on both the propensity to export, as well as on the export performance, even after controlling for size and other variables. It is significant at 1% for patenting firms and firms with innovation sales, (*patent* and *innsales*, significant at 1%, for both equations). Innovation expenditures do not have a positive impact on the export performance, but is not significant. However it does not have any impact on firm's export desicion.

With respect to organisational strategies in hi-tech firms, it is seen that an organisational strategy focused on increasing the market share in firms has a profound impact on export performance, but it does not determine a firm's propensity to export, *mktstg* is positive and significant only for the export intensity equation. Firms that emphasise the importance of post-product-development strategies, by embedding them in its organisation structure, show greater export performance.

At the same time, strategy on innovative product and services do not necessarily improve export performance in firms, *prdstg* is negative and significant for the export intensity equation. This could be because these firms are in the product development stage, devoting all their resources towards the development of novel, efficient and innovative products, at low cost, and not necessarily focusing on post- product development strategies, such as marketing and expanding sales abroad.

Firm size does not determine the propensity to export in hi-tech firms (see Table 8.12. Nevertheless, firm size is important in determining the export intensity of hi-tech firms, due to the scale advantage. *Size* is significant at 5%. This suggests that larger the firm's resource, greater is ability to enter new and capture greater export markets. It can be concluded that firms with larger resources in terms of employees, innovation sales and patents, perform well in terms of good export performance. In addition, the lack of firm resources (such as finance), which are perceived as an important obstacle, also greatly influence their exports. The results also suggest that above a certain threshold, size no longer plays a significant role. The variable *size*^{2} has a significant negative impact on the export performance confirming that after a certain size, increase in size for large firms does not generally increase its export performance. In fact, a non-linear relationship is evident here (Lefebvre et al. 1998, 2001).

The economic obstacles encountered by firms seem to be an important issue so far as their export performance is concerned (Acs et al. 1997; Fujita 1995). The variable *ecobst* is positive and significant for the export intensity equation, and has no effect on export propensity. Firms attaching great importance to (and overcoming) these financial constraints that hamper innovation shows greater export intensities.

With respect to hi-tech external networks, the results show that it is an important determinant of export performance. Maintaining greater alliance intensity with government organisations seems to greatly influence exports. The *govnet*, is positive for both equations, but is significant only for the export intensity equation. Firms collaborating with government bodies are able to gain access to important information on export incentives and the tax benefits they provide, and on markets. They also assist in providing the facilities, finance, skills, contacts and technological information that are essential for firms competing in international markets.

The customer (*cusnet*), and research (*resnet*) networks, do not determine export intensity, nor the export propensity in hi-tech firms. Additionally, the entrepreneur's competencies and technological expertise (derived from previous employment) and their overseas and international networking seems to be a very important factor in determining the export performance of firms (Coviello & Munro 1995). The variable (*intenp*) has a significant positive effect on the export intensity.

8.7 Conclusion

This chapter presents a detailed picture of the performance of high technology firms internationally. In the first part of this chapter high technology networks are analysed, providing an in depth understanding of the internationalisation of hi-tech firms with respect to their global alliances with various alliance partners. Specifically, it provides insights into how different are the collaborations of internationally focussed firms in comparison to firms with no international collaborations. It is seen that internationally focussed firms pursue greater networks compared to domestically networked firms. These firms network more as a result of their innovation activities, in particular involving in product innovation and patenting. Also, it is found that, the greater number of alliances of firms that pursue international collaborations arise mainly because they network more, specifically with research organisations, suppliers, customers and competitors. Further, both small as well as large sized internationally focussed firms are seen to foster external networks.

By analysing the export performance of hi-tech sample, this chapter further contributes to the vast literature on export performance in firms. The use of three export measures in the preliminary analysis on the export-size and export innovation relationship, thus allowed a detailed picture of high technology export performance. It indicates that larger firms are more export intensive with respect to their propensity to export; exports as a share of their total sales; and to reaching wider markets. Sales increase with the size of the firm for the regions Europe & outside Europe, where as they decrease with size, for sales in Scotland and locally.

With respect to innovation-export relation, it can be concluded that innovation has a positive influence on the export performance of firms. Innovative firms are more export intensive compared to non-innovative firms. Their propensity to export, their exports as a share of total sales and their exports in wider markets, are all greater for innovative firms. Moreover, of the innovative firms, a higher level of innovation activity is seen to enhance greater export sales. Higher levels of innovation in firms, in terms of both innovation output and input (such as new products launched, patent granted and in-house R&D capability), have a great influence in boosting the export performance of firms. It can be accepted here that it is a prerequisite, in the case of high technology to be very innovation intensive and to be competitive in order to enter, and capture greater exports and wider markets.

The main contributions are that a broad set of measures and novel variables are used in the estimation of the determinants of exports in high technology firms. The specification and estimation methods used are most conclusive, and robust results are provided.

Chapter 9 High Technology Firm Networks & Embeddeddness- - An Overview & Analysis

9.1 Introduction

This chapter unveils the complex and dynamic networks in which the firms in 5 technology-based sectors in Scotland are embedded. By analysing the extent of hi-tech networks and embeddeddness it contributes to the growing literature on the link between innovation and network in firms (Chesbrough 2003a; Hagedoorn 2002; Silverman & Baum 2002; Rominj & Albaldejo 2002; Porter & Ketels 2003), and to the regional innovation networks literature. It has policy implications too, especially since Scotland's industrial policy is built around an extensive cluster policy (SE 1998), with an emphasis within the clusters to use networks, both national and international (see chapter 1, sec. 1.5 & chapter 4, sec. 4.4).

Theoretical concepts of 'Industrial Districts' (Brusco 1998; Marshall 1920), 'Regional Innovation Systems' (Cooke 2001b; Cooke et al. 1997), and 'Innovative Milieu' (GREMI Aydolt 1985; Cappello 1999; Camagni 1996), suggest that embeddedness in networks, and interdependence among agglomeration of firms stimulates innovation (see chapter 1 sec. 1.4). The networks are analysed here by drawing on the 'Innovative Milieu' concept, characterised by spatial proximity, dynamic uncertainty reduction mechanism, informal links, and collective-learning process (Camagni 1995; Lawson & Lorenz 1999). Evidence based on 'Innovative Milieu' in the regions of Sophia-Antipolis (Longhi & Quere 1993), Cambridge (Segal, Quince, Whittaker 2000; Garnsey 1993), California (Scott 1992) etc. suggests that the establishment, success and growth of small technology-intensive firms benefit from location within a cluster, of such firms, due to the advantages of informal and formal networking, linkages and information flows within such a complex (Aydalot & Keeble 1988). However, quantitative and comparative research describing innovative milieu are rare (Sternberg 2000). The GREMI studies are an exception but are based on a case study approach. Valid cross-sectional studies that can derive the necessary, sufficient conditions for an innovative milieu by quantitative methods are so far lacking (Bergman et al. 1991). This chapter aims to:

- Provide deep insights into the dynamic networking behaviour in hi-tech firms.
- Uncover the extent of networks, by analysing various vertical and horizontal linkages.
- Examine the spatial network pattern and see if proximity increases alliance intensity.
- Determine the extent of embeddeddness in local networks, formal and informal links.
- Analyse firms' network patterns, with respect to heterogeneity in size.

Empirical firm-level evidence stresses the positive impact of networks on a firm's innovation and performance (Ritter & Gemünden 2003), new product sales, (Criscuolo & Haskell 2003, Janz et al. 2004, Lööf & Heshmati 2002); patenting, (Vanhaverbeke et al. 2004); sales growth, (Cincera et al. 2005). However, research has been focussing more on product innovations (Harris et al. 2001), often ignoring the link between networks and other forms of innovation, (e.g. incremental, process, organisational innovations). The type of partner, firms engaged in networking appear to be related to the type of innovation occurring (Freel 2003). There is no consensus regarding the appropriate network configuration for successful innovation, by comparing networking across different types of innovation. Research often tends to focus on networks with suppliers and customers and less on how the diversity of partners facilitates innovation. The role of third parties like trade and professional associations, the institutional mechanisms facilitating networking that is important for developing informal relationships, and its subsequently effect on innovation are under-researched (Pittaway et al. 2004). This suggests areas for further investigation.

Chesbrough (2003a) suggests that many innovative firms have shifted to an open innovation model using a wide range of external actors and sources to help them achieve and sustain innovation (Laursen & Slater 2006). The importance of diversity of relationships in networks has been shown to have an impact on innovativeness (Kaufmann & Tödtling 2001; Baum et al. 2000). It can enhance the breadth of perspective, cognitive resources and overall problem solving capacity (Hambrick et al. 1996). Goerzen & Beamish (2005) finds that multinational enterprises with more diverse alliance networks experience lower performance than those with less diverse alliance networks. Here the networks is categorised into 7 types, i.e. supplier, customer, competitor, research, government, trade & professional and finance. Each of these is further analysed across 5 regions: local, Scotland, UK, Europe & outside Europe.

Section 9.2 gives the summary statistics for the sample. Section 9.3 compares the network pattern and frequency of contact in different networks, to see if a firm's proximity to collaborators increases the network intensity. Section 9.4, tests the hypothesis: Are SMEs more dependent upon external networks than large firms for innovation? The embeddeddness aspect is explored in section 9.5. This enables, principally:

- An in depth understanding of the strength of firm's vertical alliances with their suppliers and their customers in various locations.
- Detailed exploration of the research networks and trade & professional association networks. Further, work is presented on:

- Firm's network patterns with government bodies facilitating and supporting innovation at the local, regional and national level are analysed.
- Collaboration with competitors and financial organisations.

9.2 Summary Statistics - Percentage of Firms

The majority of firms in the sample have external alliances on innovation (96%). Of these 83.44% have international alliances. The mean number of alliance is 31 and the mean alliance per employee is 5.16. There is strong positive correlation between the different networks as indicated by Table 9.1.

Table 9.1 Correlation between Alliance Intensity of Different Collaborators

Kendall's tau_b	Supplier	Customer	Competitor	Research	Government	Trade
Customer	.692** .000 151					
Competitor	.480** .000 129	.450** .000 129				
Research	.553** .000 131	.553** .000 131	.659** .000 126			
Government	.466** .000 129	.432** .000 129	.592** .000 123	.592** .000 124		
Trade	.394** .000 125	.376** .000 125	.412** .000 121	.491** .000 121	.570** .000 121	
Finance	.391** .000 129	.344** .000 129	.524** .000 126	.504** .000 125	.625** .000 123	.586** .000 122

** Correlation is significant at the 0.01 level (2-tailed).

Table 9.2 Firms Engaging in Networks in various Locations (%)

	Local	Scotland	UK	Europe	Outside Europe
% of Firms	62.91%	88.08%	93.98%	70%	77%
χ^2	10.073	87.583	113.649	23.053	45.623
df	1	1	1	1	1
Asymp. Sig.	.002	.000	.000	.000	.000

With respect to alliances across regions, a significantly high percent of firms is engaged in networks in all 5 regions (χ^2 significant at 1%, see Table 9.2). The highest was for the UK, followed by Scotland, outside Europe, Europe and local. The data reveal that a significantly large percent of firms networked with each of the 7 collaborators. χ^2 test statistics confirms that a significantly high percent of firms collaborate across all partners, the highest percent of firms was observed in customer and supplier, followed by research networks, (see Table 9.3).

Table 9.3 Percent of Firms Networking with Collaborators

	Supplier	Customer	Research	Competitor	Government	Trade	Finance
% of Firms	94	94	83.4	76.2	74.2	71.5	68.9
χ^2	117.146	117.146	96.533	63.131	55.248	47.059	38.118
df	1	1	1	1	1	1	1
Asymp. Sig.	.000	.000	.000	.000	.000	.000	.000

There is no significant difference in the percent of firms networking across different collaborators, (χ^2 test statistic 3.87 < critical value of 16.81 significant at 1%, df=6), nor across different locations (χ^2 test statistic 8.28 < critical value of 13.28 at 1% significance, df=4). However, on further analysis an underlying difference is evident. A cross tabulation of the percent of firms with networks across partner and by locations enabled column-wise and row-wise comparisons (see Table 9.4).

Table 9.4 Percentage of Firms with Networks- Location Cross Tabulation

	Local	*Scotland*	*UK*	*Europe*	*Outside Europe*
Suppliers	44.4	62.3	82.1	50.9	54.9
Customers	28.5	62.9	75.5	51.7	46.4
Research	20.5	30.5	22.5	10.6	13.2
Competitors	9.3	22.5	39.1	32.5	44.4
Government	16.6	36.4	31.8	7.3	5.9
Trade	13.2	27.2	35.8	13.2	21.2
Finance	16.6	32.5	20.5	7.9	9.9

- On comparing the percent of firms column-wise (in different regions), it is seen that the proportion is not the same across all 5 regions. This is true for most collaborators (χ^2 significant at 1%, df=4) except for research, where there is no significant change, the percent of firms engaging in research alliances does not differ, irrespective of research partner's location, (χ^2 statistic 12.38 < critical value 13.28, 1% significance, df=4).
- On comparing the percent of firms row-wise (for different collaborators), it is seen that significant differences exist in the proportion of firms across 7 collaborators. It is true in all regions. (χ^2 test statistic > critical value for all regions (df = 6, 1% significance).

It can be concluded that majority of hi-tech firms networked with multiple collaborators in various locations. This emphasises the importance that hi-tech firms attach to strategic alliances (Nesta & Mangematin 2004; Baum & Silverman 2000; Liebeskind et al. 1996; Fischer & Varga 2002; Love & Roper 1999; Harris et al. 2001). However, the percent of firms engaged in networks, differs for different collaborators, and for all locations. Moreover, the firms engaged in networks with any one type of collaborator are seen to vary with their location, except for research alliance.

9.3 Analysis of the Firm's Alliance Intensity with Different Collaborators

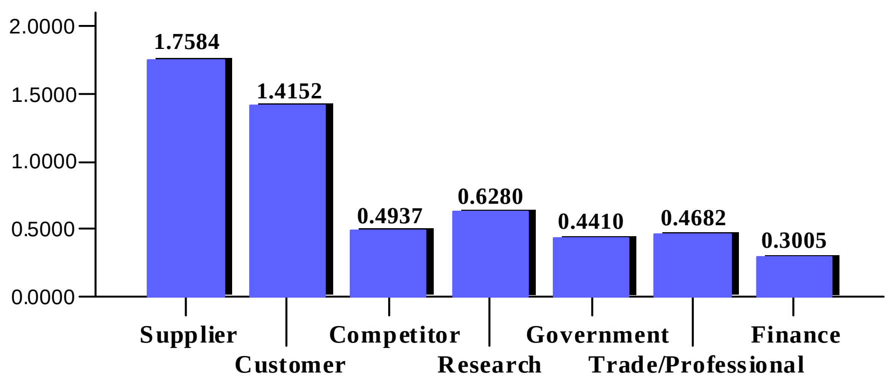
It is imperative for firms to maintain a portfolio of multiple alliances with a number of different collaborators for its competitiveness (Zahra et al. 2000). The intensity of their networks varies according to the purpose of the alliance and also the type of partner (Belderbos et al. 2004). Baum et al. (2000) suggest that variation in biotech start-up firm's alliance network composition rapidly produced significant differences in their performances. This section exposes the strength of firm's various alliances by examining the:

- Alliances with each of the 7 collaborators
- Frequency of contact with each of the 7 collaborators, Further it tests the following:
- Does a firm's proximity to collaborators imply stronger networks?

9.3.1 Number of Networks

The mean number of alliances by network type indicates that firms network most with suppliers (9.4), closely followed by customers (8.1). The mean alliances with research organisations, was close to 5 and for competitors was 3.33. The mean alliances with government organisations were 2.74, finance was 2.67 and trade/professional associations were 2.55. The average alliance per employee was much higher for supplier and customer alliances, compared to other networks, as displayed in Figure 9.1. The ANOVA test confirms that there exist significant differences in the mean across different collaborators, (F = 8.59, df = 6, significant at 1%). The Post-Hoc test further reveals that this difference is due to a higher mean for customer and supplier alliances compared to the those for competitor, government, trade, and finance; and that the networks with suppliers is significantly greater than for research.

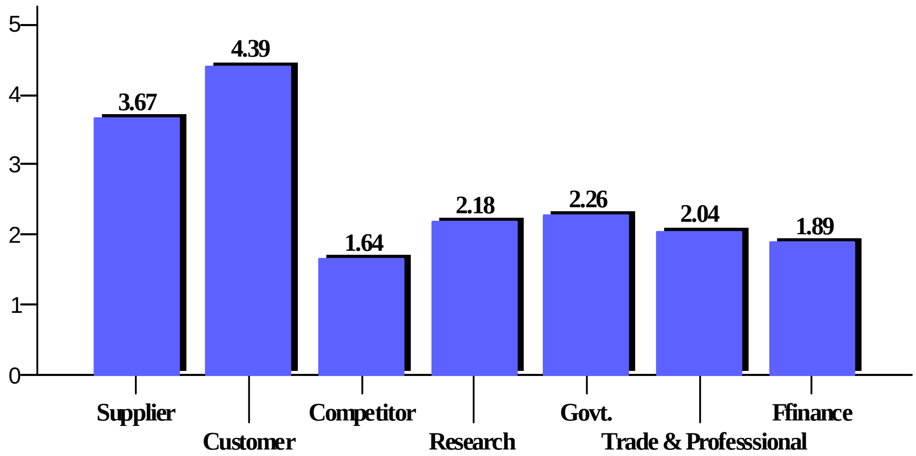
Figure 9.1 Mean Alliance per Employee



9.3.2 Frequency of Contact

This section explores the following question: 'Is there any specific pattern in the firms' networks with regards to frequency of contact, across different networks? It is analysed in terms of firm's rating on contact frequency in their networks, measured on a 6-point Likert scale (0 to 5, where 0='no contact' & 5='very frequent contact'), (see chapter 5 on questionnaire design). Figure 9.2 displays the mean contact frequency ratings, by collaborator.

Figure 9.2 Mean Frequency of Contact



The customer and supplier networks had very high frequency of contact compared to the rest (Yli-Renko & Sapienza 2001; Kaufmann & Tödtling 2001). In decreasing order it is highest for customer, followed by suppliers, government, research, trade, finance and lowest is for competitor alliances. The ANOVA test confirms that contact frequency is significantly different across collaborators, (F=61.85, df=6, 1% significant). The Post-Hoc test reveals that the difference is due to a higher mean for customer and supplier alliances compared to those for a competitor, government, trade, and finance. It is also evident there is minimal contact with competitors. On comparing the percent of firms at each point on the frequency scale across different collaborators, it is evident there is significant difference. The χ^2 value is significant at 1% for all except for research alliances. Table 9.5 presents the % in each category in the 6-point scale by network type. It is evident that in the case of customer and supplier alliances, a significantly higher percent (χ^2 significant at 1%, df=5) of firms have higher contact rating, and in the case of competitor alliances, a significantly low proportion has high ratings, (χ^2 significant at 1%, df=5). For research alliances the percentages are not significantly different. With respect to government, trade and finance, a very low percent of firms lie in the higher end of the scale and more are towards the middle.

Table 9.5 Frequency of Contacts by Collaborators: % of firms

	No Contact	*Infrequent*	*Less Frequent*	*Frequent*	*More Frequent*	*Very Frequent*	
Suppliers	6	7.3	9.3	22.5	17.2	37.7	100
Customers	6	0.7	3.3	9.3	21.1	59.6	100
Competitors	16.1	32.1	31.4	16.1	1.5	2.8	100
Research	18.2	21.9	13.9	25.6	10.2	10.2	100
Government	18.2	11.7	21.9	29.3	10.9	8	100
Trade	20.6	14	27.2	22.8	8.8	6.6	100
Finance	23.5	18.4	27.2	15.4	8.1	7.4	100

9.3.3 Alliance Intensity and Proximity

This section aims to identify whether proximity is a factor in determining the alliance intensity of firms. Here the network patterns in different regions are examined for all collaborators, to see if network contact intensity increases as a result of proximity to its partners. Table 9.6 presents the strength of contact in different alliances across regions. It is evident that the mean contact frequency of hi-tech firms in its various networks is the same, irrespective of the location of network partners. The ANOVA test for difference in mean contact frequency across regions is not significant for most collaborators except finance, where ANOVA test shows significance at 1% (F= 6.685, df = 4). A detailed analysis of the network pattern with each collaborator is undertaken next, providing important insights into a firm's dynamic networks.

Table 9.6 Frequency of Contact by Location

	Local	*Scotland*	*UK*	*Europe*	*Outside Europe*
Suppliers	3.94	3.90	3.72	3.97	3.83
Customers	4.63	4.49	4.41	4.40	4.53
Research	3.48	3.20	2.82	3.69	2.85
Competitor	2.50	2.24	2.03	2.12	2.00
Government	3.36	3.33	3.23	3.91	3.30
Trade/ Professional	2.90	3.05	2.70	2.85	3.02
Finance	2.56	2.47	3.29	3.58	3.93

- **Supplier Networks**

The integration of suppliers in the innovation process has been highlighted as one of the factors leading to breaking innovation (Kaufmann & Tödtling 2001; Perez & Sanchez 2002; Romijn & Albu 2002). The SMEs in particular gains from the use of upstream vertical alliances in many ways, through increased quality and responsiveness, and cost reductions

(Silverman & Baum 2002; Arend 2006). Belderbos et al. (2004) find that supplier cooperation focused on incremental innovations, and on improving the productivity of firms, because productivity increases may be more reflective of incremental innovations affected by collaborative R&D aimed at cost reductions. The hi-tech sample reveals intense networking with suppliers. 94% of the firms in the sample network with suppliers. The mean frequency of contact is 3.67 on a scale from 0 to 5, which means firms more frequently are in contact. Significantly more of firms in the sample had very frequent (38%), more frequent (17.2%) and frequent (22.5%) contacts. χ^2 significant at 1%, df = 4, (test statistic 42.95 > critical value 13.28, see Table 9.5).

Analysing the network pattern region-wise, it is seen that the percent of firms networking with suppliers differs across regions, (χ^2 significant at 1%, df =4), it was greater for UK compared to other regions, (see Table 9.4). However, hi-tech firms maintain close contact with their suppliers irrespective of their location. The ANOVA test for difference in mean contact across regions is not significant (see Table 9.6). A high intensity across regions is also evident in that the majority of firms maintain very close contacts with their suppliers across all regions; 46% in Local, 52% in Scotland, 50% in UK, 57% in Europe and outside Europe, (see Table 9.7 that gives the cross tabulation of percent of firms in each category of the frequency scale by location). This indicates that a hi-tech firm's high contact intensity in supplier links is not influenced by proximity.

Table 9.7 Supplier Frequency of Contact by Location: % of firms

	No Contact	***Infrequent***	***Less Frequent***	***Frequent***	***More Frequent***	***Very Frequent***	***Total***
Local	0	4	9	28	13	46	100
Scotland	0	2	5	27	14	52	100
UK	0	7	6	24	13	50	100
Europe	0	6	9	17	11	57	100
Outside Europe	0	4	17	12	10	57	100

The hi-tech firms greatly value supplier networks, as the effective integration of suppliers in new product development processes can have a significant impact on cost, quality, technology, speed and responsiveness of buying companies (Ritter & Gemünden 2003). This enables firms to develop wider expertise during the development process (Romijn & Albaladejo 2002). It also helps to reduce concept-to-customer cycle time, costs and quality problems. Finally, it leads to higher levels of productivity and quality (Perez & Sanchez 2002), and provides a clearer focus on the projects that require joint development (Ragatz et al. 1997).

- **Customer Networks**

Customers are considered to be the most important partners in idea generations, identifying market opportunities, and in reducing the risk associated with market introductions of the innovation (Kristensson et al. 2002; Prahalad & Ramaswamy 2000; von Hippel et al. 1999). Particularly, when products are novel and complex, this requires adaptations in use by customers and also helps to ensure market expansion through innovative products (Belderbos et al. 2004; von Hippel 1988; Tether 2002). Empirical study shows that customer involvement tends to be useful at the beginning, in terms of idea generation, but is less so during the developmental process where the manufacturer tends to lead (Conway 1995; Gemünden et al. 1992). In the case of hi-tech firms, the data here shows that customer alliances are very important; 94% have customer networks, and the mean frequency of contact is 4.39, on a scale from 0 to 5, which is very frequent. The high customer alliance intensity is also indicated by the significantly high percent of firms (60%) having very frequent contact, χ^2 is significant at 1%, df = 4, (test statistic 14.75 > critical value 13.28).

With respect to alliances in different regions, there is a significant difference in the percent having alliance across region (χ^2 is significant at 1%, df =4), and it was lower in local (see Table 9.4). However, the firms have very frequent contact irrespective of their location. An ANOVA test for difference in mean contact frequency across regions are rejected, as contacts are very high for customer alliances in all regions (see Table 9.6). The percent of firms with very high frequency of contact is also high and similar, irrespective of the location of the customer. Table 9.8 gives the cross tabulation of firms in each category of the frequency scale by location).

Table 9.8 Customer Frequency of Contact by Location: % of firms

	No Contact	*Infrequent*	*Less Frequent*	*Frequent*	*More Frequent*	*Very Frequent*	*Total*
Local	3	0	3	7	13	74	100
Scotland	3	0	5	13	16	63	100
UK	1	1	4	10	19	65	100
Europe	0	2	6	10	19	63	100
Outside Europe	0	0	5.5	9	11	74.5	100

The data show that proximity to customers is not important to maintaining intense close contacts. Networking with customers is viewed as being important because it not only allows firms to learn of existing needs, but also leads to the discovery of new needs, in advance of competition, and assists during incremental innovation (Bruce & Rodgus 1991). Customer networking in the early stages of product innovation will assist in the development of ideas. It reduces the risks (Gemünden et al. 1992; Ragatz et al. 1997), and the innovator can learn the likely market potential of a product idea (Conway 1995).

- **Research Networks**

Cooperation with universities and research institutes is generally more aimed at radical breakthrough innovations that may open up entire new markets or market segments (Tether 2002; Monjon & Waelbroeck 2003). Research networks tend to be most important where the innovation is relatively radical in orientation (Fritsch 2001). It enhances the innovation capabilities of firms (Rominj & Albaladejo 2002; Audretsch & Stephan 1996; Caneils & Rominj 2003). This reflects the absorptive capacity argument that firms require a certain level of internal R&D in order to assimilate the external information on innovation, especially the tacit information on new and complex technology sourced from research organisations that are difficult to codify (Dosi 1988; Cohen & Levinthal 1989, 1990; Zahra & George 2002). Other than these direct benefits, they also play an important role as independent network brokers and intermediaries for firm interacting with them, (Kaufmann & Todtling 2001; Bougrain & Haudeville 2002). Past evidence also shows that they contribute to innovation networks, usually through informal-personal networks (Bower & Keogh 1996). 83.4% of the firms in the sample have research alliances. The mean contact frequency is 2.2 on a scale of 0 to 5. However, when it comes to research alliance in different regions, the contact is more frequent (see Table 9.6). Firms have more frequent contact with research partners in Europe, followed by local partners, compared to research collaborations in the UK and outside Europe. Moreover, the percent of firms having very frequent contact in alliances is greater locally (33%) and for Europe (31%) as shown in Table 9.9.

Table 9.9 Research Frequency of Contact by Location: % of firms

	No Contact	*Infrequent*	*Less Frequent*	*Frequent*	*More Frequent*	*Very Frequent*	*Total*
Local	0	13.3	10	23.3	20.3	33.3	100
Scotland	0	13	17.5	30.5	15	24	100
UK	0	21	23	26	12	18	100
Europe	0	6	13	19	31	31	100
Outside Europe	0	30	10	25	15	20	100

This indicates that the distant location of a firm's research partners does not affect the frequency of contact. However, the research network pattern does not differ significantly, irrespective of a research partner's location (see Table 9.4). The mean contact frequency (ANOVA test is not significant, F= .137, df = 4)) and the percent of firms engaging in research alliances does not differ significantly across regions, (χ^2 statistic 12.38 < critical value 13.28, 1% significant, df = 4). In short, the evidence suggests that hi-tech firms have intense research networks, but they are not as intense as customers or suppliers. However, all research alliances have the same intensity, irrespective of the location of research collaborators. It is vital to hi-tech firms to have intense research networks and to strike the right balance by having both global as well as local networks, in order to increase their innovation capability and performance, and to be at the forefront of cutting-edge technology (Rominj & Albaladejo 2002; Cohen & Levinthal 1990; Monjon & Waelbroeck 2003; Zahra & George 1999).

- **Competitor Networks**

Belderbos et al. (2004) found for a large sample of Dutch firms that competitor and supplier cooperation focused on incremental innovations, improving the productivity performance of firms (Hagedoorn & Schakenraad 1994; Gulati 1995; Powell et al. 1996). In this sample, network intensity is very low in the case of competitor alliances. 62.91% of hi-tech firms networked with competitors. The mean frequency of contact with competitors is only 1.64, which is quite low on a scale of 0 to 5. Significantly, a large proportion of firms have infrequent (32%) or less frequent contacts (31%) and 16% have no contacts at all (χ^2 significant at 1%, df = 4, test statistic 52.68 > critical value 13.28, see Table 9.5). Only 16% of the firms have frequent contact.

When it comes to contact with competitor alliances in different regions, it is seen that firms generally have low mean contact intensity in all regions (see Table 9.6). However, contacts are slightly higher for local and Scotland alliances, but the ANOVA test is not significant. Looking at the percent of firm across regions, it is evident that a significantly greater percent of firms have global competitor alliances compared, to local and Scotland competitor networks. 44.4% had competitor alliances outside Europe (see Table 9.4). It is seen that the percent of firms having very frequent contacts (21.5%) and frequent contacts (21.5%) is significantly greater for alliances that are local, (see Table 9.10). The percent of firms with frequent contact are significantly more for local and Scottish locations compared to UK and beyond.

Table 9.10 Competitor Frequency of Contact by Location: % of firms

	No Contact	*Infrequent*	*Less Frequent*	*Frequent*	*More Frequent*	*Very Frequent*	*Total*
Local	7	36	14	21.5	0	21.5	100
Scotland	6	38	16	28	3	9	100
UK	7	34	32	20	2	5	100
Europe	6	29	36	21	2	6	100
Outside Europe	6	37	31	18	3	5	100

In short, firms have less frequent or infrequent contacts with their competitor collaborators, and the ones with whom they have better contacts are mostly located locally or in Scotland (Lu & Beamish 2001). This indicates that in the case of competitor alliances distance does matter. Firms are found to maintain better contacts with competitors situated closer to them. However, proximity is not important in terms of significantly greater networking by firms, as the data show that most firms networked with competitors located outside Europe.

- **Government Networks**

Government organisations provide the incubation facilities, finance, skills, contacts and technological information that are essential for innovation capacity building (Kogut 1988; Das & Teng 2000). This is shown to impact on innovation (Rothschild & Darr 2003; Benfratello & Sembenelli 2002). Government institutional mechanisms, designed specifically to create and facilitate networks, come in many forms. The most common forms are clusters, incubators (Rothschild & Darr 2003), and centres for co-operation like science parks, but their degree of effectiveness is unclear (Staber 2001). Although National and Regional Centres for collaboration are cited in the Porter report (Porter & Ketels 2003) as valuable for networking, none of the evidence directly addresses their value in terms of networking and innovation. These issues are addressed here.

In this data, 74.2% of firms do government collaborations. The mean frequency of contact with government is 2.26 on a scale of 0 to 5. A significantly greater percent of firms are in the middle of the scale (frequent contact on a scale of no contact to very frequent contact), as is evident from Table 9.5. However, when it comes to government alliances in different locations, the contact is more frequent in all regions (see Table 9.6). The firms maintain more frequent contact in their networks in Europe (3.91) compared to other regions but the difference in mean across regions is not significant by an ANOVA test. However, the percent of firms with government networks is significantly different (χ^2 significant at 1%, df=4) across regions (see Table 9.4). It is more in Scotland (36.4%) and UK (31.8%) compared to other regions. Looking at intensity of contacts with government across regions (see Table 9.11), it is seen that 45.5% of firms with alliances in Europe, 40.7% of firm with alliances e in Scotland and 35% of firms with alliance in the UK have frequent contact. In general, greater number of firms with networks with government is in Scotland and the UK. However, proximity to government bodies do not increase its contact. It confirms that distance does not matter to firms in that firms have frequent contacts with their global government collaborators in Europe and also in Scotland in the same way.

Table 9.11 Government Frequency of Contact by Location: % of firms

	No Contact	*Infrequent*	*Less Frequent*	*Frequent*	*More Frequent*	*Very Frequent*	*Total*
Local	0	4	29	17	25	25	100
Scotland	3.7	5.6	11.1	40.7	20.4	18.5	100
UK	0	8	17	35	23	17	100
Europe	0	0	0	45.5	18.2	36.4	100
Outside Europe	0	11	11	45	0	33	100

- **Trade & Professional Networks**

Third parties, such as professional associations, trade associations and publicly funded bodies specifically aimed at promoting innovation (such as technology transfer centres) have a positive impact on the development of inter-organizational networks and innovation (Conway 1995; Grotz & Braun 1997; Hanna & Walsh 2002). Third parties have a dual role in promoting innovation. They ideally act as neutral knowledge brokers, but also act as important conduits for the development of informal relationships (personal relations between individuals), which are the basis for the development of network relationships, particularly between small firms (Hanna & Walsh 2002). Professional associations were found to provide useful forums for promoting the development of socio-cultural infrastructure (Grotz & Braun 1997). Robertson et al. (1996) finds that professional associations are not necessarily neutral conduits in the diffusion process. Research in the UK automotive sector highlighted that some professional associations have a pro-innovation bias and promote particular versions of 'best practice' that are not necessarily appropriate across all firms in a sector.

For the hi-tech sample, 71.5% of firms engaged in these networks. The majority of firms have less frequent or frequent contacts, in alliances with their trade partners. The mean frequency of contact was 2.04 on a scale of 0 to 5, less frequent contact. The percent of firms on the higher scale is significantly low: 20% has in fact no contact at all (see Table 9.5). However, alliance in different regions shows frequent contact (see Table 9.6). It is the same in all regions, as an ANOVA test for difference in mean is not significant, indicating that proximity to local or Scotland trade partners does not result in greater contact. The percent of firms networking in different regions is however significantly different (χ^2 significant at 1%, df=4, see Table 9.4). It was highest in UK (35.8%) and Scotland (27.2). It is seen that the percent of firms with frequent contact was 40% in local, 42.4% in Scotland, 30.2% in UK, 40% in Europe and 35% outside Europe (see Table 9.12).

Table 9.12 Trade Frequency of Contact by Location: % of firms

	No Contact	*Infrequent*	*Less Frequent*	*Frequent*	*More Frequent*	*Very Frequent*	*Total*
Local	0	10	25	40	15	10	100
Scotland	0	10	17.5	42.4	17.5	12.5	100
UK	6	15	26.4	30.2	13	9.4	100
Europe	0	15	20	40	15	10	100
Outside Europe	0	3	31	35	22	9	100

- **Finance Networks**

The importance of appropriate venture finance and loan finance for innovation has been widely documented (Harding 2000). Past evidence shows that they are important within the networking infrastructure, for the commercialisation of innovation (Florida & Kenney 1988a). Co-operative investment benefits both investing firms and entrepreneurial hi-tech firms. Investors act as key brokers within innovation networks, introducing partners to prospective and current firms with whom they have invested (Bygrave 1987, 1988). Past evidence supports this point, in both the formal and informal marketplace for venture capital funds. The establishment of venture capital firms locally, in established technology centres, enables firms to prosper via the higher concentration of good deals (Keeble et al. 1998, 1999). Such finance networks, when well developed, attract further start-up activity, creating a self-reinforcing cycle (Florida & Kenney 1988b). Past evidence on informal investment networks (e.g. business angel) also highlights its importance during a firm's pre-start-up, start-up and early growth stages of development.

In this sample 68.9% of firms had finance networks. Hi-tech firms had less intense finance networks than one might expect from the literature, as the firms had less frequent contact with them, (mean is 1.89 on a scale of 0 to 5). Moreover, a significantly small percent of firms had frequent (15%), more frequent (8%) and very frequent (7%) contact with their financial partners, (χ^2 test statistic 19.9 > critical value of 13.28 at 1%, df = 4). The majority of the firms are on the lower scale, with no contact, infrequent or less frequent contacts (see Table 9.5). Alliances were significantly more frequent outside Europe, followed by Europe and UK (see Table 9.6), indicating that firms value finance networks in distant locations and that proximity is not necessary to enable greater contacts. Nevertheless, significantly few firms networked with finance bodies in Europe (7.8%) and beyond (9.9%).

In short, it is evident here that only a small number of firms have finance alliance that are distant and international, but these alliances are more intense in terms of close contacts and the opposite is also true. Majority have finance alliance in Scotland and local but these alliances are less frequent. Finance network pattern is significantly different across regions. The proportion of firms engaged in finance network (χ^2 significant at 1%, df=4) and the mean contact frequency (ANOVA significant at 1% F= 6.685, df = 4), significantly varies across regions. This indicates that the finance alliance pattern is influenced by location of the finance partner but the fact that close proximity increasing network contact intensity is not evident.

9.4 Networking and Firm Size

The central hypothesis considered here is that SMEs are more dependent upon external networks than large firms for innovation. There has been considerable research on the role of networks in promoting firm innovation. In particular, SME's have been considered to rely more heavily on external knowledge networks as an input to innovation than do large firms. The smaller the firm, the more heavy is the usage of external knowledge networks (Feldman 1994, Almeida & Kogut 1997, Love & Roper 1999; Rogers 1998). The alliance activity in SME-favored knowledge intensive industries grew by 20 to 25 percent over last two decades (Narula 2004). Intuitively, one might assume that SMEs are more dependent on their external environment than are large firms. It is generally accepted that SMEs are usually locally based, and strongly influenced by what happens in their local community, whereas large firms tend to be international and more flexible in the location of their production. Previous studies suggest that although SMEs are generally more dependent on local customers and suppliers, this is less characteristic of innovative firms (Oakey et al. 1988).

Nevertheless, large firms do have advantages in external communication, since it is much harder for an SME to update its technical knowledge than for a large firm. The latter are able to send people to conferences and seminars all over the world (Rothwell & Zegveld 1982). Hence, the existence of local networks is vital for SMEs (Almeida & Kogut 1997). This importance also stems from the SMEs' inability to internalise all the elements of the innovative process (Maillat 1990, 1995) and because network will provide economies of scale that SMEs otherwise would not have attained (Camagni 1991).

Drawing upon such existing literature, the networks intensities of small and large firms are compared, using a tobit model. The network intensity of firms is measured as the number of alliances per head. There is a strong, negative, significant correlation between the number of alliances per employee, for all collaborators and size, measured as both employment and turnover (see Table 9.13). Tobit estimates were computed for each of the seven collaborators, with network intensity as the dependent variable, and employment size as the independent variable, in the first instance. Tobit estimates for turnover size as the independent variable also gave the same results. The estimation results are given in Table 9.14. In the case of hi-tech firms, network intensities have a highly significant negative impact, as measured by both the size variables. It is significant at 1% for all, except for finance networks, which is significant at 5% as is evident from the table (bottom row). Thus in the case of hi-tech firms, it is the small and medium firms that have greater alliance intensity compared to large firms (Rogers 2004; Love & Roper 1999). A means of increasing SMEs' survival rates is through alliance (Baum et al. 2000; Baum & Oliver 1991), and for some SMEs strategic alliances are critical to improve their competitive positions.

Table 9.13 Correlation between Firm Size and Alliance Intensity

Kendall's tau_b		Employment	Turnover
Suppliers	Correlation Coefficient Sig. (2-tailed) N	-.577** .000 151	-.413** .000 150
Customers	Correlation Coefficient Sig. (2-tailed) N	-.596** .000 151	-.367** .000 135
Competitors	Correlation Coefficient Sig. (2-tailed) N	-.475** .000 129	-.352** .000 129
Research	Correlation Coefficient Sig. (2-tailed) N	-.616** .000 131	-.464** .000 131
Government	Correlation Coefficient Sig. (2-tailed) N	-.450** .000 129	-.338** .000 129
Trade	Correlation Coefficient Sig. (2-tailed) N	-.438** .000 125	-.355** .000 125
Finance	Correlation Coefficient Sig. (2-tailed) N	-.345** .000 129	-.330** .000 129

**Correlation is significant at the 0.01 level (2-tailed).

Table 9.14 Tobit Estimation Results: Firm Size and Alliance Intensity*

Dep. Var	Ind. Var	a	b	t	P-value	F	R Square
Supplier	lemp3	3.778**	-.895**	-4.530	.0000	20.99**	.123
Customer	lemp3	1.109**	-.774**	-6.789	.0000	329.96**	.689
Research	lemp3	.828**	-1.108**	-5.622	.0000	416.38**	.763
Competitor	lemp3	.772**	-.848**	-18.4	.0000	338.50**	.727
Govt.	lemp3	-.162	-.963**	-3.097	.0021	346.45**	.731
Trade	lemp3	.869**	-.232**	-3.821	.0001	25.32**	.170
Finance	lemp3	-.550**	-.650*	-2.343	.0191	172.03**	.575

** sig. at 1% * sig. at 5%

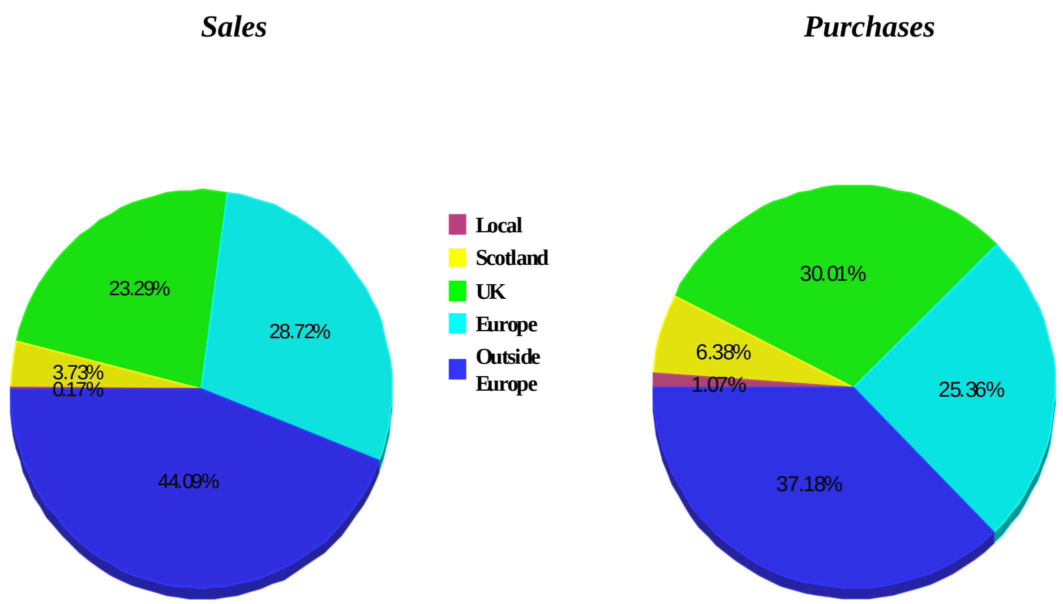
9.5 Embeddeddness

Chapter 8, on internationalisation of hi-tech firms, gave a brief insight into the embeddeddness aspect of hi-tech firms, where it focused on exports and international networks. In this section, various measures were used to do an indepth analysis of the extent of embeddeddness in hi-tech firms. Specifically the distribution of total sales, and purchases, in 5 different regions, the extent of firm's recruitment links in Scotland and entrepreneur's links are examined.

9.5.1 Distribution of Sales & Purchase in the Five Regions

The hi-tech firms are globally oriented when it comes to sales and purchase distribution. The pie chart presented in Figure 9.3 show the distribution of hi-tech sales and purchases.

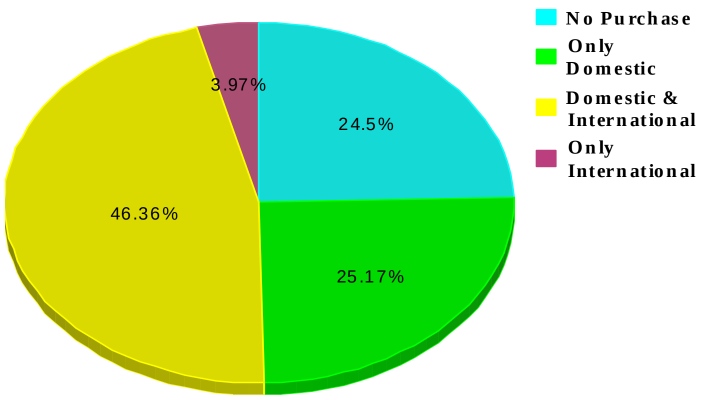
Figure 9.3 Distribution of Sales & Purchases



72.81% of the total sales and 62.54% of the purchases are international. In fact the highest proportions of these two are in markets that are outside Europe, i.e., 44.09% of sales and 37.18% of purchases. The firms exhibit less embeddedness with respect to local and Scottish sales and purchases. In fact, the highest proportion of purchases is from outside Europe (37.18%) followed by the UK (30.01%), and Europe 25.36%. In the case of sales, the highest are, in outside Europe (44.09%), followed by Europe (28.72%) and UK (23%). The proportion of total sales and purchases in Scotland markets are very low, at 3.73% and

6.38% respectively. The proportions, which are local, are 1.07% and 6.38%, for sales and purchases respectively. The different categories of firms with respect to purchases are displayed in Figure 9.4.

Figure 9.4 High Technology Purchases- % of Firms



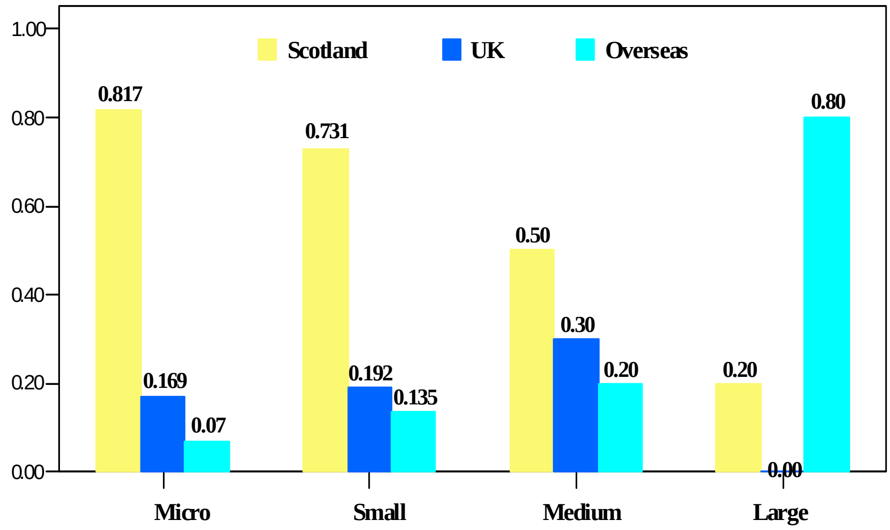
On examining this, it is evident that half the firms are internationally sourcing, and only 25% of the firms are sourcing domestically. Moreover, the percent of firms with international purchases are significantly greater (significant at 1%, df=3, $\chi^2 = 54.272$). Thus the hi-tech firms do not exhibit embeddeddness when it comes to purchases.

9.5.2 Entrepreneurial Links

Here the extent of embeddeddness of hi-tech firms is evaluated by analysing the three different categories of entrepreneurs that started their firm, from Scotland, the UK and overseas. The data reveal that entrepreneurs from Scotland ranked first, followed by entrepreneurs from the UK, and finally by overseas entrepreneurs (ranked the last). 70% of the entrepreneurs are from Scotland, 17% are from UK and only about 13% of the firms had international entrepreneurs who were instrumental in starting the firm. Further tests were performed to see whether any size related pattern existed with respect to the three categories of entrepreneurs. Differentiating the firm's entrepreneurs by firm size led to certain interesting insights (see Figure 9.5).

Significant differences exist between firm types, when it comes to the category of entrepreneurs that are from Scotland and overseas. The Anova test is significant for Scotland (significant at 1%, df = 3, F= 5.521) and for Overseas Entrepreneurs (significant at 1%, df=3, F=8.679). Moreover, the mean number of Scotland based entrepreneurs is seen to be decreasing with firm size, and is in contrast to the overseas-based entrepreneurs, which are seen to increase with firm size. The Post-hoc tests further revealed that there exists significant mean differences between large firms, compared to small and medium firms with respect to Scottish and overseas entrepreneurs. 82% of the entrepreneurs of micro-firm type are Scottish based and only .07 % is overseas based. In the case of small firms, more than 73% are Scotland based and only about .14% is overseas based. For medium firms, only half the firms had Scotland based entrepreneurs, 30% were UK based and 20% from overseas. For large hi-tech firms, only 20% were Scottish based and 80% were overseas entrepreneurs. This indicates that the entrepreneurs of hi-tech firms are increasingly seen to be Scottish based in the case of micro, small and medium firms. In contrast, for the large high technology based firms, the entrepreneurs are increasingly seen to be overseas based. There is more local embeddeddness for small firms compared to large firms (Almeida & Kogut 1997).

Figure 9.5 Distribution of Entrepreneurs by Firm Size



9.5.3 Recruitment Links

In term of recruitment, a significantly large percent of hi-tech firms recruited potential employees from Scotland (more than 72% of the firms, see Table 9.15)). Differentiating by size it is seen that there are significant differences in the proportion of firms recruiting between the sizes (see table 9.15).

Table 9.15 Staff Recruitment from Scotland by Size

	Micro	Small	Medium	Large	Total
% of firms recruiting staff from Scotland	55.56	88.89	80	100	72.41

An Anova test for difference in mean is significant at the 1% level (df =3, F= 8.902). A Post-hoc test reveals that the difference real, as far less micro firms recruit staff from Scotland, compared to others. An explanation for this may be that micro firms do not recruit any staff at all, and that is reflected here, and this is not because they are any less embedded.

9.6 Conclusion

This chapter set out to analyse the dynamic networking pattern in which hi-tech firms are embedded. It was analysed here by categorising the networks into 7 networks type. The evidence from the data reveals that hi-tech firms greatly value their vertical linkages i.e., the customer and supplier alliances. They are highest in terms of both number of alliance and contact frequency. These alliances are mainly dealing with product development, product testing, the production process and cost reduction, all of which require close contact and strong linkages due to the tacit nature of the know-how about complex technology. The firm’s networking is great with suppliers, followed by customers; but it is the customer networks where firms have the maximum contacts, followed by suppliers.

On the other hand, horizontal alliances of hi-tech firms are less intense compared to customer and supplier alliances. Networks with competitor are least frequent. This may be because the purpose of these alliances is to seek and to receive information, ideas and knowledge on technology, overseas and niche markets, which requires mostly a one-time contact or so. But with regards to research alliance, government alliance and finance alliance, this is not the case. Firms display frequent contacts with them. Firms nurture these alliances mainly for resource sharing, and hence this requires frequent contacts. The facilities of research and government labs, expensive technical and human resources from universities and grants and other forms of finances, are crucial in the case of the hi-tech firms’ survival and competitiveness. However it seen that proximity to the network partners does not increase the intensity of networks, in terms of greater contact frequency. Moreover, in the case of hi-tech firms the small and medium firms have greater network intensity compared to large firms. Hi-tech firms are less embedded with respect to sales and purchases. They are globally oriented. But when it comes to recruitment and the entrepreneur’s background, the hi-tech firms are less global and exhibit more embeddeddness.

Chapter 10 High Technology Innovation, Networks and Performance: A Simultaneous Approach

10.1 Introduction

This chapter deals with the estimation of an econometric model developed specifically for this research on innovation, networks and performance of firms, in the hi-tech sectors of Scotland. The structural model explains the firm performance by innovation output, and the innovation output by innovation investment. It builds on the work of many researchers who have analysed the two-way relationship between innovation and performance at the firm level, using a simultaneous equation model approach (Janz et al. 2004; Mairesse & Mohnen 2003; Klomp & van Leeuwen 2001). The model comes under the conceptual framework of the CDM model, (Crépon et al. 1998) that brings together three important, but largely separated lines of empirical research into one encompassing model, (Hall & Mairesse 2004) viz. the determinants of R&D investment in firms (Freel 2003; Rominj & Albaldejo 2002; Oerlemans et al. 2001), the knowledge production functions (Pakes & Griliches 1984; Acs et al. 1994; Love & Roper 2001), and the Cobb-Douglas production function (Jaffe 1986; Griliches 1995; Wakelin 2000).

The structural model developed here contributes to the growing literature on the link between innovation and performance in firms along a number of lines.

- It is one of the few studies to estimate the causal effect of innovation investment on innovation output, and the causal effect of innovation output on firm performance in the manufacturing and service industries, using a simultaneous equations framework (Ebersberger & Lööf 2005; Benavente 2006; Loof 2004; Loof & Heshmati 2002).
- The traditional analysis of the relationship between R&D and productivity is extended and developed by using new firm-level data from primary sources, not previously available, and a novel structural economic framework that endogenize innovation in explaining the performance heterogeneity.
- The interaction between the different stages of innovation, networks and firm performance is analysed by using novel measures, in a simultaneous framework that solves for both sample selection bias and simultaneity bias.
- The results provide insights into the dynamic innovation process in hi-tech firm, the effect of firm's external networks, and demand-pull and technology-push factors.

- It captures the direct impact of these factors on each of the different stages of the innovation process (innovation decision, innovation input and innovation output) in hi-tech firms, and how these factors indirectly impact performance.
- The (relative) importance of variables referring to the external environment and firm-specific innovation characteristics diverges from the estimated impacts of the single-equation approach when taking into account the simultaneous nature of the variables, (Klomp & van Leeuwen 2001).
- The results are of great relevance to the current Scottish policy on technology clusters, which emphasise on the networks, innovation, and inter-dependence of firms, as seen in chapter 4.

The approach takes into account that not all firms are engaged in innovative activities. When only the innovation sample is used in some part of the model, the firms are not randomly drawn from the larger population, and selection bias may arise. Therefore, as in the CDM model, a selection equation is added to the system. The innovation literature (Pakes & Griliches 1984) has also suggested that, due to the complicated process from new ideas to innovation output or performance, a knowledge production function should be estimated not as a single equation but as a system of equations. When several links of the process of transforming new ideas to performance are considered in a simultaneous equation framework, one possible problem is that some explanatory variables are often not exogenously given and lead to simultaneity bias. Thus as in the CDM model, the model developed here accounts for both selectivity and simultaneity issues, (see chapter 2, section 2.3 & chapter 3, section 3.2.4).

However, the model developed here extends the CDM model extensively, in terms of model formulation, specification, variables and their transformations, and estimation methods, by taking into account the statistical features of the rich unique data, collected on hi-tech firms, and the specific problems encountered.

1. Specifically, the simultaneity is extended to all three equations in the second part of the model, unlike the CDM model, where only the last two equations are estimated simultaneously.

2. The selection equation is more through as it is based on the innovation investment decision (Loof & Heshmati 2002), and not the R&D investment decision (Crepon et al. 1998), or the product innovation decision (Ebersberger & Lööf 2005).

3. The model investigates the feedbacks links at different stages of the innovation process (Klomp & van Leeuwen 2001; Stoevsky 2005), based on the ‘success breeds success' hypothesis (Mansfield 1968) which states a positive impact of innovation success on further innovation activities and on the innovation success in following years. The model incorporates feedback links from performance to the innovation input (Stoevsky 2005), and to the innovation output (Janz et al. 2004), and feedback from innovation success to the innovation decision, (Janz & Peters 2002), thus explains the innovation persistence in firms, (Raymond et al. 2006; Geroski 1997).

4. This model explores how the firm's various internal resources (Freel 2003; Rominj & Albaldejo 2002; Hadjimanolis 2000; Nelson 2000; Oerlemans et al. 1998; Dosi 1988), and the external demand and technological opportunities are effectively utilised by firms (Powell et al. 2002; Cooke 2002a), to increase its innovation capacity and innovation success. Further, it estimates the importance of these factors in impacting firm performance (Cohen & Levinthal 1990; Hoopes et al. 2003; Zahra & George 2002; Henderson & Cockburn 1998).

5. It investigates the strategic orientation of the hi-tech firms, and attempts to verify which of the strategic aspects such as technology-push (Rosenberg 1974), market-pull (Schmookler 1966), and cost-push lead to increased innovation input, as well as increased innovation output in these firms, (Mairesse & Mohnen 2003).

6. The analysis of the effect of a firm's different networks on its innovation input, innovation success, and its performance are undertaken by controlling for the impact of knowledge spillovers from different sources (Zucker et al. 1998a, b; Feldman 2001), and controlling for its internal innovation effort (Belderbos et al. 2004). The network of hi-tech firm is captured by creating three variables, viz., customer, research, and government alliance intensities, respectively.

7. It allows the verification of several stylised facts on the innovation activity in small and large hi-tech firms in Scotland. It thus extends the analysis on the hi-tech performance heterogeneity across firm size, performed in Chapter 7.

Section 10.2 describes the data set and variables used. Section 10.3 explains the model formulation, the new features in the model, and how it is different from the CDM, and studies based on it. Section 10.4 illustrates the estimation methods and the econometric specifications used. Section 10.5 presents the results, where the results of a single-equation approach, is compared with the results from a simultaneous-equation model.

10.2 The Data and Variables

The data set defines the framework for the selection and specification of the variables in the econometric analysis. The sample of 151 hi-tech firms included in the investigations consisted of firms in the optoelectronics (17.72%), microelectronics (20.25%), digital media (20.25%), life science (20.89%) and software (20.89%) sectors in Scotland, (see chapter 6 on sampling methods). The data constituted information on key performance and innovation variables for a 5-year period, firm characteristics, internal resources, external opportunities, networks and embeddeddness, (see chapter 5 on questionnaire design). Unless otherwise noted, all data relate to the year 2003. Sophisticated innovation indicators are used to capture the dynamic innovation process (see Chapter 2, section 2.5). It involves the measurement of all stages from R&D to patents, new product development to innovation sales (Hagedoorn & Cloodt 2003) in hi-tech firms. This was enabled by drawing on the vast empirical work on determinants of innovation in firms, knowledge networks and embeddedness (see Chapter 3).

The various demand-pull (Schmookler 1966), and technology-push (Rosenberg 1974) factors effecting innovation are incorporated in the model, by drawing upon the research and theoretical concepts of Absorptive Capacity (Zahra & George 2002; Cohen & Levinthal 1990); Alliance & Innovation (Chesbrough 2003a, von Hippel 1998); Knowledge Spillover (Caniels & Rominj 2003; Cortright & Mayer 2002); ‘Innovative Milieu’ (Keeble et al. 1998; Camagni 1991); and firms’ internal resources (Nelson 2000; Oerlemans et al. 1998). Table 10.1 presents the variable’s descriptions.

10.2.1 Descriptive Statistics

Of the 151 firms in the sample, 92% (139 firms) have introduced new or significantly improved products in the past 5 years (1999–2003), or are in the process of introducing them in the next 5 years, (see chapter 6, section 6.4.6). Whereas, only 80.13% of the firms in the sample (121 firms), have innovation expenditures. The overlap of firms reporting innovation input and output is 115, constituting 76.16% of the full sample, 82.73% of the sample with product innovation and 95.04% of the sample with innovation input. This captures the fact that not all innovative firms can attribute their innovation output to firm’s internal innovation expenditures, 17.27% of the firms involved in product innovation have zero expenditures. Table 10.2 and 10.3 presents the descriptive statistics of the variables in the innovative and non-innovative samples.

Table 10.1 Variable Descriptions

QUANTITATIVE VARIABLES

Innovation Indicators

1. *Innovate* - Innovation Investment Decision, dummy variable, 1= yes, 0= no
2. *Inninp* - Innovation Input Intensity, innovation expenditures per employee
3. *Innsales* - Innovation Sales Intensity, sales from new products & services launched in the last 5 years, as a proportion of total sales.
4. *Patent* - Patent intensity, patents granted & filed per employee, in the last 5 years
5. *Humcap* - Human Capital, % of technical & managerial staff with university degree
6. *Train* - Training status, dummy variable, 1= firm undertaking staff training
7. *Rddep* - R& D department status, dummy variable, 1= firm having R&D department

Performance Indicator

8. *Perform* - Returns from innovation investments, ratio of turnover to innovation expenditure

Firm's General Characteristics

9. *Size* - Number of employees
10. *Age* - Year since inception, range from 1year to 5 years and above
11. *Export* - Export status, dummy variable, 1= firms undertaking exports
12. La*bpdt* - Labour Productivity, ratio of turnover to employee

Network Intensity & **Embededdness**

13. *Resaln* -Research Alliance Intensity, No. of alliances per employee with research partners
14. *Govaln* -Government Alliance intensity, No. of alliances per employee with govt. bodies
15. *Cusaln* -Customers Alliance Intensity, No. of alliances per employee with customers
16. *Locnet* - Local Networks, dummy variable, 1= firms with external networks that are local

QUALITATIVE VARIABLES

Organisational Strategies *Firm's importance ratings on a 5-point Likert scale on :-*

17. *Pdtystr* - Increased productivity strategy
18. *Prodstr* - Improved products or extended product range strategy
19. *Mktstr* - Increased or retained market share strategy

Knowledge Spillover Sources *Firm's importance ratings on a 5-point Likert scale on :-*

20. *Intsrc* - Internal source of information stimulating innovation
21. *Mktsrc* - Market source of information stimulating innovation
22. *Edpsrc* - Education & public information source stimulating innovation

Obstacles *Firm's importance ratings on a 5-point Likert scale on :-*

23. *Ecobst* - Economic factors hampering innovation
24. *Frmobst* - Firm specific factors hampering innovation

The comparison of means of key variables is a preliminary indication that significant differences exists along several key parameters, between the firms with and without product innovation and (Table 10.2), and between the firms with and without innovation expenditures (Table 10.3). The innovative sample on an average is significantly larger, and has significantly more emphasis on product innovation strategies (*prodstr*), (see t-test given in Table 10.2 & 10.3). The variables representing the reasons for innovation through a number of firm strategy variables include, enhanced or extended product innovation strategy (*prodstr*), increased market share strategy (*mktstr*), and increased productivity strategy (*pdtystr*). The innovative sample attached greater importance to all these strategies, compared to the non-innovative sample. P*rodstr* is significant at 1% in Table 10.2, and at 5% in Table 10.3. *Mktstr* is significant at 5% in Table 10.2, and pdtystr at 5% in Table 10.3.

Table 10.2 Firms with & without Product Innovation - Comparison of Means

	Innovative Sample			***Non-innovative Sample***				
Variables	***Mean***	***S.Dev***	***Obs***	***Mean***	***S.Dev***	***Obs.***	***t***	***p value***
Age	**4.14**	**1.28**	**139**	**4.75**	**0 .866**	**12**	**-2.248**	**0.039**
Size	**125.65**	**518.3**	**139**	**31.25**	**40.00**	**12**	**2.077**	**0.040**
Perform	**455.04**	**4315**	**115**	**38.50**	**63.25**	**6**	**0 .237**	**0.813**
Patent	**0.241**	**0 .681**	**139**	**0.082**	**0.150**	**12**	**2.205**	**0.031**
Humcap	**78.26**	**31.87**	**139**	**84.66**	**20.91**	**12**	**-0.661**	**0.509**
Innovate	**83%**	**0.379**	**139**	**50%**	**0 .522**	**12**	**2.778**	**0.006**
Inninp	**17.13**	**33.79**	**139**	**11.60**	**20.87**	**12**	**0.556**	**0.579**
Innsales	**1.24**	**1.381**	**137**	**0**	**0**	**11**	**10.51**	**0.000**
Rddep	**42.45%**	**49.60**	**139**	**25%**	**45.22**	**12**	**1.272**	**0.225**
Export	**60.43%**	**25**	**139**	**27.27%**	**46.70**	**12**	**2.586**	**0.022**
Locnet	**47.48%**	**50.11**	**139**	**25%**	**45.22**	**12**	**1.64**	**0.125**
Resaln	**0.654**	**1.037**	**123**	**0.232**	**0.157**	**8**	**3.872**	**0.000**
Govaln	**0.449**	**0.761**	**121**	**0.308**	**0.322**	**8**	**0.519**	**0.605**
Cusaln	**1.49**	**2.54**	**139**	**0.471**	**0.861**	**12**	**3.119**	**0.004**
Intsrc	**3.98**	**1.414**	**133**	**4.29**	**0.951**	**7**	**-0.555**	**0.580**
Mktsrc	**4.24**	**1.067**	**133**	**4.29**	**0.755**	**7**	**-0.110**	**0.912**
Edpsrc	**2.05**	**1.455**	**133**	**2.57**	**1.86**	**7**	**-0.921**	**0.358**
Ecobst	**3.89**	**1.323**	**132**	**4.57**	**0.534**	**7**	**-2.946**	**0.014**
Frmobst	**2.67**	**1.40**	**132**	**2.57**	**0.975**	**7**	**0.177**	**0.860**
Pdtystr	**3.07**	**1.506**	**133**	**2.29**	**1.704**	**7**	**1.329**	**0.186**
Prodstr	**4.26**	**1.132**	**133**	**2.86**	**2.41**	**7**	**2.992**	**0.003**
Mkrstr	**3.99**	**1.411**	**133**	**2.86**	**2.41**	**7**	**1.993**	**0.048**

Table 10. 3 Firms with & without Innovation Expenditures- Comparison

	With Expenditures			*Without Expenditures*				
Variables	***Mean***	***S.Dev***	***Obs***	***Mean***	***S.Dev***	***Obs.***	***t***	***p value***
Age	**4.16**	**1.28**	**121**	**4.30**	**1.21**	**30**	**-.552**	**0.582**
Size	**143.3**	**553.7**	**121**	**16.57**	**24.60**	**30**	**2.509**	**0.013**
Perform	**434.3**	**4205**	**121**	**-**	**-**	**-**	**-**	**-**
Patent	**0.239**	**0.629**	**121**	**0.185**	**0.765**	**30**	**0.411**	**0.682**
Humcap	**79.48**	**30.65**	**121**	**75.87**	**33.69**	**30**	**0.559**	**0.577**
Inninp	**20.83**	**35.62**	**121**	**0**	**0**	**30**	**6.431**	**0.000**
Innsales	**1.22**	**1.42**	**119**	**0.830**	**1.11**	**29**	**1.388**	**0.167**
Rddep	**48%**	**50.1**	**121**	**13.3%**	**34.6**	**30**	**4.443**	**0.000**
Export	**60%**	**49.3**	**121**	**50%**	**50.9**	**30**	**0.939**	**0.349**
Locnet	**48.7%**	**50.1**	**121**	**33.3%**	**47.9**	**30**	**1.563**	**0.125**
Resaln	**0.630**	**1.033**	**110**	**0.616**	**0.907**	**21**	**0.059**	**0.953**
Govaln	**0.451**	**0.721**	**107**	**0.393**	**0.851**	**22**	**0.328**	**0.744**
Cusaln	**1.40**	**2.561**	**121**	**1.47**	**2.04**	**30**	**-0.166**	**0.869**
Intsrc	**4.09**	**1.28**	**121**	**3.42**	**1.89**	**19**	**1.96**	**0.051**
Mktsrc	**4.27**	**0.983**	**121**	**4.05**	**1.43**	**19**	**0.847**	**0.398**
Edpsrc	**2.02**	**1.40**	**121**	**2.42**	**1.92**	**19**	**-0.881**	**0.388**
Ecobst	**4.00**	**1.23**	**121**	**3.39**	**1.65**	**18**	**1.87**	**0.063**
Frmobst	**2.80**	**1.34**	**121**	**1.72**	**1.32**	**18**	**3.19**	**0.002**
Pdtystr	**3.08**	**1.47**	**121**	**2.68**	**1.79**	**19**	**1.06**	**0.290**
Prodstr	**4.30**	**1.09**	**121**	**3.53**	**1.87**	**19**	**2.55**	**0.012**
Mktstr	**4.01**	**1.40**	**121**	**3.47**	**1.89**	**19**	**1.17**	**0.251**

The innovative sample display greater innovation inputs and innovation outputs compared to the non-innovative firms. Greater proportion of firms with product innovation, incur innovation expenditures (*innovate*, significant at 1% in Table 10.2). The innovation expenditure intensity and presence of R&D department, is greater (*rddep & inninp* are significant at 1% in Table 10.3), for firms with innovation expenditures. The patent intensity (*patent,* significant at 5%), and the innovation sales intensity (*innsales* significant at 1%), is greater for firms with product innovation. The innovative sample is more export intensive (*export,* significant at 5% in Table 10.2). The performance (*perform)* is not significantly different. The importance attached to the obstacles to innovation is more for firms with innovation expenditures; firm specific *(frmobst)* and economic obstacles (*ecobst)* are significant at 1% and 10%, respectively. Firms are increasingly seen to have conceded that fundamental breakthroughs in technology or science are increasingly likely to occur outside their organizations (Gassmann & Reepmeyer 2005; Chesbrough 2003a).

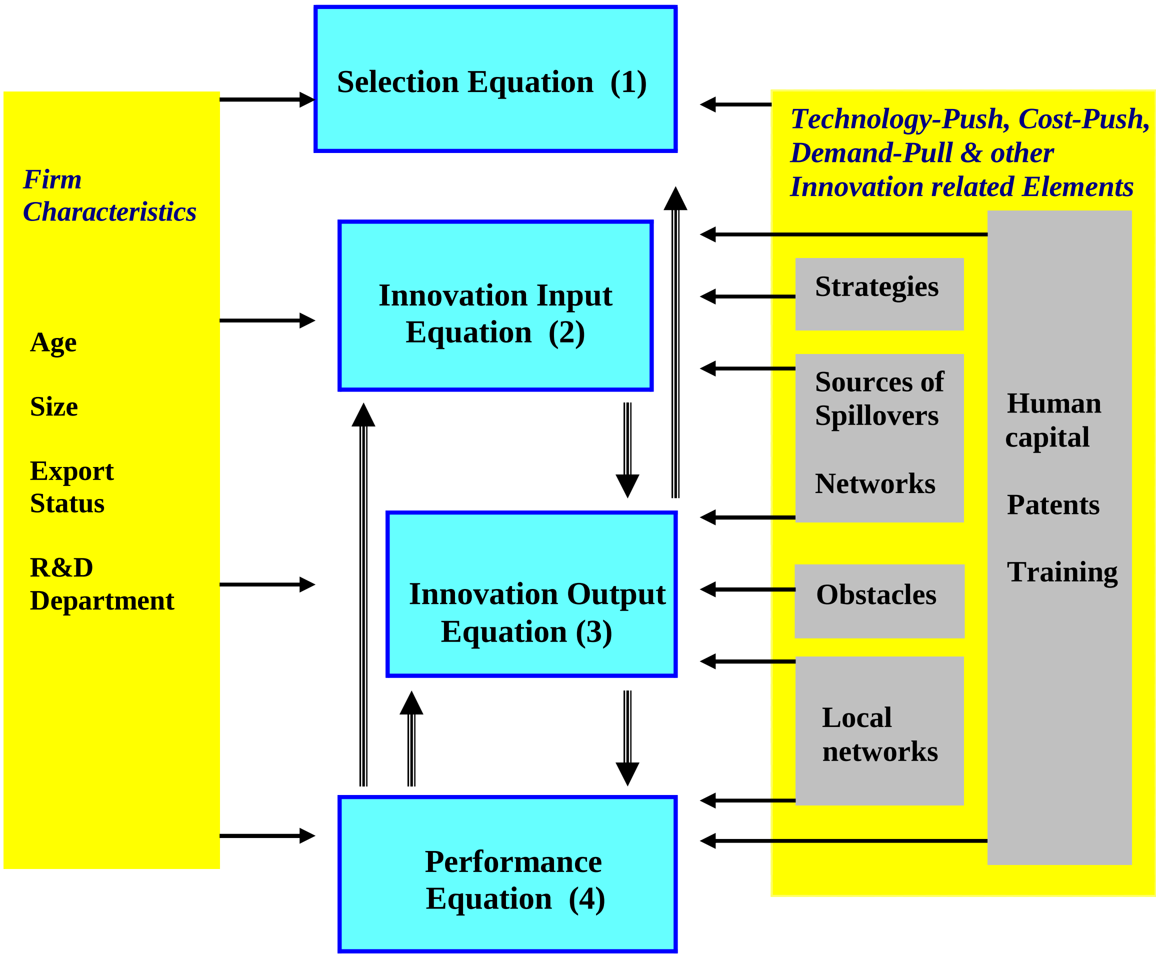
The data suggest that, with respect to the innovation networks, customer is the dominant one, followed by research and finally government, for the innovative sample, (Love & Roper 1999; Klomp & van Leeuwen 2001). The customer (*cusaln*) and research network (*resaln*) is significantly greater for the innovative firms compared to firms without product innovation, (significant at 1%, see Table 10.2). With respect to spillovers, in this research it denotes the ‘pure-knowledge-spillovers’, which describes the benefits of innovative activities of one firm that accrue to another without following market transactions, and not ‘rent-spillovers’ occurring in input-output relations (Griliches 1992; Cassiman & Veugelers 2002). The market sources (*mktsrc*) are the most critical source, followed by internal sources (*intsrc*) and the educational/public sources (*edpsrc*), for both the innovative and non-innovative samples. However, they are not significantly different for the 2 samples.

The descriptive statistics indicate that innovative firms are significantly larger, more export oriented, patent intensive and its R&D are organised in a department, denoting continuous R&D effort. It has greater customer links, followed by research links. Such firms report greater emphasis on product innovation strategies, followed by demand expansion strategies, and firm’s internal sources as great source of knowledge spillover. However, these simple mean comparisons cannot be taken as evidence of the impact of innovation input on innovation output, and that of innovation on performance, as this requires controlling for other variables like networks, strategy etc., and the joint impact of the other variables in a multivariate analysis.

10.3 Model Formulation

The applied econometric model developed here is a two-stage, four equations model, and is represented in Figure 10.1. It has three established relationships including the innovation input linked to its determinants (Equation 2), the knowledge production function relating innovation output to innovation input (Equation 3), and the production function relating performance to innovation output (Equation 4). The first stage involves selection equation (1), determining the factors influencing a firm’s propensity to innovate (have innovation expenditures), and is estimated separately. The second stage involves the last 3 equations, and can be approximated by equations 3.2 to 3.4, (see chapter 3) in the Pakes & Griliches model (1984). It is estimated in a simultaneous equations framework.

Figure 10.1 Conceptual Framework of the Model



i) ***Sample Selection Bias***- There are a number of features that are new in this model. The first one is with respect to sample selectivity. It takes into account the fact that not all firms engage in innovative activities. When only the innovation sample is used in some part of the model, the firms are not randomly drawn from the larger population, and selection bias may arise. Even though 92% of the firms have introduced or are in the process of introducing new products, not all of these firms can attribute this innovation output to their own innovation expenditures. 17.3% of these firms (24 firms) do not have innovation expenditures. The key variable innovation expenditures are zero for about 17.3% of the innovative sample (with product innovation), and for 19.87% of the full sample (30 firms). This may show up as a selectivity problem in the estimation procedure. For the application of the full model, a complete set of innovation variables and performance measures is necessary for all the firms in the sample. Common to other studies, a missing variables problem is encountered here as well. In this study, the missing variable problem arises due to the fact that, for 19.87% of the firms in the full sample and for 17.3% of the firms in the innovative sample, the performance variable is missing, as division by zero is encountered in the computation of the performance variable, (*perform* = the ratio of turnover to innovation expenditures), (see Table 10.1).

Therefore, as in the CDM model, a selection equation is added to the system. However, unlike the CDM model where the selection equation is dependent on R&D investment decision, here the selection equation is with respect to the firm's innovation investment decision, where a binary variable is equal to one if the firm has positive innovation expenditure, and zero otherwise, as in Loof & Heshmati (2002, 2006) and Loof et al. (2001). The sample selection is more thorough, as the new selection variable allows for more firms in the model (121 firms), as compared to when using R&D expenditures (104 firms). Both the innovative and the non-innovative firms are used in the selection equation and a selection corrector variable, which Heckman (1979) refers to as the inverse of Mill's ratio (IMR), is estimated. The IMR is included as an additional explanatory variable in the innovation input, innovation output and performance equations to correct for selectivity bias, as in Ebersberger & Lööf (2005).

ii) ***Simultaneity Bias-*** Another bias that is encountered is the simultaneity bias (see Greene 2003, chapter 15). When several links in the process of transforming innovation investment to performance are considered in a simultaneous framework, one possible problem to emerge is that some explanatory variables often are not exogenously given, leading to simultaneity bias. Here the innovation input intensity (*inninp*) is an explanatory variable in the innovation output equation 10.3), and innovation sales intensity (*innsales*) is one of the explanatory variables in the performance equation (10.4). Because of the endogeneity of these variables, it cannot be assumed that the explanatory variables and the disturbances are uncorrelated. As a result, an Ordinary Least Square regression applied to the Pakes and Griliches model (Eq. 10.3 to 10.4) will be biased and inconsistent.

Durbin-Wu-Hausman test was performed to investigate whether the set of estimates of the structural equations obtained by least squares are consistent or not. Accordingly, if the null hypothesis that OLS estimates are consistent is rejected, endogeniety (not every regressor is asymptotically independent of the disturbances) is present and the instrument variable (IV) estimator is preferred to the least squares estimator (David & Mackinnon 1993, p.237). However, no evidence of endogeniety between *perform* and *inninp* was found for the innovation input equation (10.2). Similarly no evidence of endogeniety was found between *perform*, *inninp* and *innsales* in the innovation output equation (10.3), and no evidence of endogeniety was found between *innsales* and *perform* in the performance equation (10.3). Failure to reject the null hypothesis does not imply that there is no endogeniety present. It suggests that there is no need for structural modelling, but failure to reject it may or may not imply endogeniety (see Geroski 1982, p150). Only under very strict conditions will failure to reject be compatible with exogeniety. Thus to improve the economic interpretations of the results and to increase the statistical efficiency, and following theoretical considerations, system estimation is adopted here. Moreover, a simultaneous-equation approach is more suitable for models that stress the importance of feedback links running from overall economic performance and the innovation process (Klomp & van Leeuwen 2001). It is useful to consider a reduced form of the model, which is the method suggested by CDM (see chapter 3, section 3.2.4), to overcome the problem of endogenous explanatory variables and derive consistent estimators. However, as an alternative to the CDM and its reduced form estimation method, an instrumental variables approach is considered here, imposing different assumptions concerning the disturbances (Loof & Heshmati 2002).

Another major modification is that, the simultaneity is extended to three equations. This is essential due to endogeniety of some of the variables. Unlike the CDM model, this model allows a feedback from the performance equation (10.4) to the innovation input (10.2) and to the output equations (10.3), *perform* is included in both innovation input and innovation output equations, as the economic performance of firms have can an impact on both the innovation input as well as the innovation output of firms, (Klomp & van Leeuwen 2001; Janz et al. 2004). Moreover, here the full sample is used in both the first and second part of the model, unlike others who used only the innovative sample in the simultaneous part.

Another feature is that, unlike the CDM model and others (Chudnovsky et al. 2006; Benavente 2006; Loof & Heshmati 2006; Mairesse & Mohnen 2003) who have used dummy variables to capture the demand-pull (Schmookler 1966), technology-push (Rosenberg 1974), or cost-push factors (Klomp & van Leeuwen 2001), the model has embedded in it, firm’s network with external organisations, the critical sources of knowledge spillovers, and the firm’s innovation strategies with respect to the demand-pull, cost push and technology-push factors. The literature highlights the relationship between technology and innovation, in the context of exploiting technological opportunities, i.e. technology-push to offer radical product innovation in contrast to focussing on an existing market need or the market pull, (Prajogo & Ahmed 2006). Betz (1998) strongly argues that firms need to maintain a balanced focus between both views in their strategy (Scherer

1982). Here three variables: the product innovation strategy (*prodstr*), market strategy (*mktstr*), and productivity strategy (*pdtystr*), are included to represent the technology-push, demand-pull and the cost-push objectives of the firm, respectively. Similarly, the impact of knowledge spillovers from market sources (customer, supplier, competitors), educational and public sources (universities, research & government), and internal sources are incorporated in both innovation input equation (10.2) and innovation output equation (10.3). The network intensity is captured by customer, research and government network, respectively (see Table 10.1).

The model allows one to examine the direct effect of networks on innovation input separately from that on the innovation output and also the indirect effect on the economic performance (see Figure 10.1). The differences in impact of these same network variables on the innovation input and on the innovation output, can illustrate the firm's specific intentions that drive the firm to form alliances (Criscuolo & Haskell 2003; Janz et al. 2004; Vanhaverbeke et al. 2004).

One important aspect is that the impact of different networks directly on the innovation input and output and indirectly on the performance, is determined by controlling for the impacts of knowledge spillovers from different sources, and firm's own innovation effort (Oerlermans et al. 2001; Fischer & Varga 2002; Oerlerman & Meeus 2002; Belderbos et al. 2004). The customer, research and government networking were selected, so as to reflect the additional impact of knowledge spillovers from the same sources, i.e., market and educational and public sources.

For the hi-tech data here, from the Tables 10.2 & 10.3, it appears that the demand-pull factors are stronger compared to the technology-push, and cost-push factors. It was evident that the market source (*mktsrc)* of knowledge spillovers, has a higher mean importance ratings than educational & public source (*edpsrc*), in both tables. In terms of the network intensity, customer network (*cusaln*) is higher than research network (resaln), whereas, with respect to the organisational strategies, product innovation strategy (*prodstr*) is most important followed by market strategy *(mktsr*), and lastly productivity strategy (*pdtystr*). But, the studies of the emergence of US biotech industry (Zucker & Darby 1996; Zucker et al. 1998a, b; Feldman 2001; Prevezer 2001), and on the UK electronics industry (Rominj & Albaladejo 2002) finds that, spillovers from universities are key to firm start-ups.

Another advancement is that, the effect of the firm's embeddedness in local links directly on its performance, and indirectly on its innovation (through performance), is incorporated in the model. A dummy variable, local networks, is a proxy for embeddedness in the performance equation (Eq. 4), (Keeble et al. 1998). Empirical evidence suggests that these knowledge flows are highly localized (Gertler & Levitte 2005). The number of new product development by firms is positively and significantly related to the number of university stars in their geographical area, (Zucker et al. 1998a). Local links are increasingly seen as being especially critical for developing basic research (Niosi 2000b), and for creating a critical mass of research capability (Cooke 2002a) in biotech firms. Moreover, empirical findings confirm that local venture capital (VC) provide key inputs, both the investment capital and the entrepreneurial and managerial know-how necessary for commercial success (Zucker et al. 1998b; Gertler & Levitte 2005; Cooke 2001b). VC links is very important to smaller, younger and more science-focused firms, who are at the early stages of development, unlike firms that have reached more advanced commercial stages of development who are more likely to attract external financing from afar, (Powell et al. 2002; Cooke 2002a). But Cortright & Mayer (2002), in a survey of US biotech firms, concludes that research activity is not very highly concentrated spatially, although commercialization efforts remained highly concentrated.

10.4 Specification and Estimation of the Model

The applied econometric model is a two-stage model incorporating Heckman's sample selection and involves 4 equations, the first of which is estimated separately and the last three of which are estimated in a simultaneous equations framework. The first stage involves selection equation (1), and the second stage involves the last three equations.

Selection Eq.
$$g_i = \begin{cases} 1 \text{ if } g_i^* = x_{1i}b_1 + u_{1i} > 0 & \textit{firms with innovation expenditures} \\ 0 \text{ if } g_i^* = x_{1i}b_1 + u_{1i} \leq 0 & \textit{firms without innovation expenditures} \end{cases} \qquad 10.1$$

Innovation Input
$$k_i = \alpha_{2q} q_i + x_{2i} b_2 + IMR + u_{2i} \qquad 10.2$$

Innovation Output
$$t_i = \alpha_{3k} k_i + \alpha_{3q} q_i + x_{3i} b_3 + IMR + u_{3i} \qquad 10.3$$

Performance
$$q_i = \alpha_{4t} t_i + x_{4i} b_4 + IMR + u_{4i} \qquad 10.4$$

g_i* is the latent innovation investment decision variable dependent on x_1, a vector of variables that explains the firm's decision. g_i is a binary variable, the observable counterpart of g_i* which is equal to 1 if the firm has innovation expenditures, and zero if it does not have any such expenditure. k_i, t_i and q_i describe innovation expenditure intensity (*inninp*), innovation sales (*innsales*) and performance (*perform*) respectively. x_{2i} , x_{3i} and x_{4i} are vectors of various variables explaining innovation input, innovation output and performance of firms. In contrast to the CDM model where the same set of variables is used as x_{1i} and x_{2i}, here the x_{1i} and x_{2i} are only partially overlapping as in Loof et al. (2001) and Janz & Peters (2002). The b's and α's are the unknown parameter vectors. u_{1i}, u_{2i}, u_{3i} and u_{4i} are i.i.d. drawings from a normal distribution with zero mean, jointly correlated for the simultaneous part. The variables *inninp, innsales,* and *perform* are considered endogenous in the system. The exogenous variables are the size, age, human capital, patent intensity, the obstacles to innovation and finally the demand-pull, cost-push and technology-push factors constituting the different network intensities, different sources of knowledge spillovers, and different strategies. The 4 dummy exogenous variables are embeddedness in local alliances, presence of an R&D department, and participation in export activity and training (see Figure 10.1).

10.4.1 First Stage of the Model- *Selection Equation (1)*

In the first stage, the firms decide whether to have innovation expenditures or not. The selection equation is estimated using a probit model (Janz & Peters 2002) to determine the factors that explain the investment decision and their impact on the probability of innovation investment. As mentioned only 80.13% of the firms in the full sample have innovation expenditures, and this would mean that there would be a sample selection bias if only the firms with such expenditures are selected for the second part of the model. The selection equation is estimated for the full sample, (151 observations). The estimates of the probit selection equation are used to construct an inverse Mills ratio, which is an additional variable in equation 10.2, 10.3 & 10.4 of the second part of the model to correct for sample selection bias (Ebersberger & Lööf 2005). The explanatory variables for the selection equation are size, age, patent intensity, labour productivity and human capital (Cohen & Klepper 1996; Klette & Kortum 2002). The commercial success of innovation in the past is another explanatory variable that will effect the decision, the variable innovation sales is included, (Janz & Peters 2002, see the casuality structure of the model displayed in Table 10.4). In addition to this, the perceived obstacles to innovation, the three different sources of knowledge-spillover variables, and the organisational strategies denoting the demand-pull, cost-push and technology push factors respectively, are included (see Figure 10.1). The two dummy variables are the presence of an R&D department and the export status.

Empirical evidence stresses the importance of an internal R&D department in firms (see chapter 3, Section 3.3.1). Kleinknecht & Reijen (1992) verified the positive effect of having a formal R&D department when co-operating with R&D institutes. Veugelers (1997) finds that the effect of R&D co-operation is not significant in R&D intensity unless firms have an R&D infrastructure (Meeus & Oerlemans 2000; Contractor 1983). Gassmann & Reepmeyer (2005) stress that balancing the right size and structure of the R&D department has thus turned out to be one of the primary objectives in R&D management, in a study on pharmaceutical industry. The dummy variable R&D department indicates the firm's organization of the R&D in a formal, routinised, and continuous manner, and is included in all four equations of the model.

10.4.2 Second Stage of the Model

The second part of the model involves simultaneity. In this part the innovation input equation (10.2), innovation output equation (10.3) and the performance equation 10.4) are estimated jointly as a system for all 151 firms. The innovation expenditure intensity *(inninp*), innovation sales (*innsales*) and performance variables (*perform*) are expected to be endogenous in the system. The estimation method of iterative 3SLS (3-stage least squares) is the one that is used for reporting. The advantage is that it is asymptotically equivalent to FIML (full information maximum likelihood), but not so sensitive to specification errors as is FIML.

However, another important issue is whether the b's are constant across all firms in the full sample. If they are not, then the implication is that regressions should be run on sub-samples of the full sample, since there is no justification for pooling firms together. This issue is caused by coefficient heterogeneity, which arises because some of the relationships will vary for firms with innovation expenditures compared to those without. Hence the second part of the model involving equations 2, 3 and 4 is estimated for the sub-sample as well, i.e. for the firms with innovation expenditures, (121 firms). This is done using tobit estimation, and involves only the firms that decide to have innovation expenditures, i.e., those with positive innovation expenditure only. The same sets of variables that are used in the simultaneous part are used for the tobit part of the selectivity model so as to facilitate a comparison. Moreover, both the estimation techniques solve for sample selection bias.

Since the innovation intensity, innovation output and performance variables are continuous, with only lower censoring at zero, tobit estimation technique was considered to be the most appropriate. This allows us to compare the second part of the model, using the two different estimation techniques:

1. Simultaneous model involving full sample (all 151 firms) versus tobit model that involves the sub-sample (only firms with innovation expenditures, 121 firms).
2. Simultaneous model solving for the simultaneous bias arising from the inherent endogeniety of certain variables, versus tobit model that ignores simultaneity bias.

a) Innovation Input Equation (2)- The innovation expenditure intensity (*inninp*) is the endogenous dependent variable in the innovation input equation as in Ebersberger & Lööf (2005), and Mairesse & Mohnen (2003), and not R&D intensity, as is in CDM, (Crepon et al. 1998; Benavente 2006). The factors that influence the innovation expenditure intensity have been examined empirically in several studies (refer chapter 3, section 3.3). Previous research found that innovation intensity is influenced by firm size, export intensity, R&D on a permanent base, prior sales level, education of the employees, external support (subsidies), obstacles to innovation, information for innovation, organisational strategies or innovation objectives, and cooperation (Klomp & van Leeuwen 1999). A cross–country study by Lööf et al. (2001), concludes that the innovation investment in Finland, Norway and Sweden were positively influenced by internal source of information, strategy on extending the product range, customers and domestic cooperation with customers. The effect of size was ambiguous as it was negative for Finland, positive for Norway, and in-significant for Sweden. Kleinknecht & Oostendorp (2002) on studying the causality between R&D intensity and export intensity in firms finds that export intensity had a significant positive effect on its R&D intensity. In this research, the innovation input is determined by the size, patent intensity, human capital, network intensities with customer, research and government organisations, source of knowledge spillovers and organisational strategies. Three dummy variables control for the presence of an R&D department, export status and the implementation of staff training, all influence the innovation input. α_{2q} captures the feedback effect from the performance equation to the innovation input equation as in Stoevsky (2005). The inverse Mills ratio from the probit model reflects the difference in the probability of innovation investment decision and is an explanatory variable.

b) Innovation Output Equation (3)- In equation 10.3, the innovation output equation, the most important explanatory variable is the innovation expenditure intensity (Crepon et al. 1998). It is seen that new product development in hi-tech sectors requires, the integration and combination of specialised knowledge inputs from different sources (Cohen & Levinthal 1990; Brown & Eisenhardt 1998), as there are often a number of subsystems incorporated in hi-tech products and requires compatibility with a broader technology platform and different technology standards (Anderson & Tushman 1990). Knowledge inputs in the area of markets, manufacturing and design etc., has to be accessed from other firms, as strictly in-house development of such complementary knowledge is often not economically feasible (Teece 1986). Zahra & Nielson (2002) finds that both company's internal and external sources significantly influence its technological commercialisation, and that integration strengthens the contributions of manufacturing sources to technological commercialisation. Their results suggest that strong internal technical manufacturing capabilities and using external human resource, manufacturing sources, significantly improve the number of new products and commercialisation speed.

The following explanatory variables are incorporated in equation (3): the internal, market and education/public sources of incoming knowledge spillovers, and the networks with customer, research and government bodies. These variables represent the internal and external sources and the technological opportunities that can hep in commercialisation of innovation in hi-tech firms. It also captures the demand-pull and technology-push factors. Firms facing problems with respect to internal resources and internal capabilities severely affect its innovation sales (Zahra & Nielson 2002). The firm's importance attached to obstacles to innovation such as economic and firm specific factors are the other two variables that are included. Dummy variables, controlling for the presence of an R&D department, export status and local networking are the other determinants of firm's innovation output (refer Figure 10.1). The success in economic performance of a firm can influence its innovation sales by injecting funds that are important for the development and commercialisation of the research findings (Stoevsky 2005; Janz et al. 2004). α_{3q} captures the feedback effect from the performance to the innovation output (see Table 10.4)

c) Performance Equation (4)

In the last equation (10.4), the important explanatory variable is innovation sales. The 4 dummy variables determining performance are: presence of an R&D department, implementation of staff training, local networking and export status. The firm's patent intensity and human capital (Hitt et al. 2001; Hatch & Dyer 2004) are included. Age and size are controlled in all four equations (see Table 10.4). The inverse Mills ratio is included in equations 10.2, 10.3 & 10.4.

Table 10.4 Causality structure of the model

	Selection Eq.	Innovation Expenditure	Innovation Sales	Performance
Age	X	X	X	X
Size	X	X	X	X
R&D department	X	X	X	X
Export Status	X	X	X	X
Innovation Expenditure			X	
Innovation Sales	X			X
Performance		X	X	
Networks		X	X	
Sources of Knowledge Spillover	X	X	X	
Obstacles to Innovation	X		X	
Organisational Strategies	X	X		
Human capital	X	X		X
Labour Productivity	X			
Training		X		X
Local Embeddeddness			X	X
IMR		X	X	X

10.5 Estimation Results

The results of the estimation are discussed here. The results and findings contribute considerably to our existing knowledge on the structure of innovation and the inter-dependence between innovation input, innovation output and performance. The results of the simultaneous equations model, accounting for endogeneity, and correcting for sample selection bias, are compared with the estimation results of tobit model, with sample selection, but which ignores the inherent simultaneous bias and interdependence of innovation input, innovation output and performance.

10.5.1 Selection Equation (1)

The probit estimate for the selection equation has a highly significant χ^2 and the ability of the probit estimates to distinguish between the two groups is very high, correctly predicting 116/119 of the firms with expenditures. As reported in the surveys by Cohen & Klepper (1996) and Klette & Kortum (2002), size has been found a highly significant firm determinant to engage in innovation, as in Loof & Heshmati (2006, 2002) and Ebersberger & Lööf (2005). The propensity to innovate significantly increases with firm's innovation strategy on product innovation, innovation sales intensity and for firms doing R&D on a routine, continuous process, (see Table 10.5).

Firm specific obstacles to innovation such as lack of skilled personnel drive firms to invest in innovation, in order to compensate for such shortcomings. *Frmobst* is positive and highly significant. Economic obstacles, like financial constraints (*ecobst*), also have negative impact, but are not significant. Generally, firms decide to invest in innovation to achieve cost-efficiency and internal innovation capability that can increase its competitiveness. However, firms who already have the innovation capability, in terms of intellectual property, and cost-efficiency by means of labour-productivity, do not see the need to devote their resources to do internal R&D. Greater patent intensity and higher labour productivity, reduces the firm's propensity to innovate. The variable *patent* and *labpdt* are negative and significant.

The results suggest that the cost–push factors reduce the propensity to innovate in hi-tech firms. Firms with increased labor productivity and patent intensity, is an indication of their higher efficiency and cost control, achieved through process innovations. This reflects the findings by Mairesse & Mohnen (2003) that cost-push elements tend to reduce the innovation input intensity in firms. Moreover, the variable on productivity or cost-push strategy of firms, (*pdtystr)* has a negative impact, but is not significant.
It is the technology push factors that increase the hi-tech firm's propensity to innovate, and not cost-push or the demand-pull factors. Innovation strategy on product innovation significantly encourages the firm to innovate, *prodstr* has a significant positive effect on the firm's decision to innovate. There is evidence of persistence of innovation as well (Geroski 1997), the variable sales from new products and services as a proportion of the total sales (*innsales*) have a strong positive significant effect.

Market strategies on expanding markets/capturing new markets, does not affect the propensity to innovate, *Mktstr* does not show any impact, Firms with overseas markets also do not exhibit greater probability to have innovation expenditures, *export* is non-significant, (see Table 10.5). Such firm's resources are diverted to post R&D aspects, such as commercialisation, launch of products, and internationalisation. The finding that the propensity to innovate does not increase with export orientation, is in contrast to Ebersberger & Lööf (2005) for firms in Nordic countries, and Janz et al. (2004). It could be because their selection variable is based on the product innovation decision.

Although none of the spillover variables are significant when controlling for other factors such as size, patent, R&D department, innovation sales, exports, strategies on innovation etc, they do suggest certain tendencies. The spillovers from the market, and educational/public sources, provide less incentive for the firm to invest in innovation, (see Table 10.5), as the firm can easily access the know-how required for its innovation capability building, from customers, suppliers, competitors, and research organisations in the form of technology embodied in the product, processes or components (or part of them) that are outsourced, or simply by informal links, that helps in technology transfer. When the internal spillover is high there is less incentive to invest in R&D, (*intsrc*) has a negative impact. The explanation is that, firms who already have patents, filed or granted, have accumulated substantial internal knowledge source for innovation, are innovation intensive anyway, and so less likely to incur innovation expenditures.

The estimation results of the selection equation suggest that the choice of having innovation expenditures in Scottish hi-tech firms is influenced by scale effects (Love & Roper 2002; Kleinknecht & Mohnen 2002; Vossen & Nooteboom 1996) and the firm's innovation strategy on product innovation. Seven facts are evident here:

1. The cost-push factors reduce the hi-tech firm's propensity to innovate. Greater labour productivity, higher patent intensity, and productivity strategy, all emphasis the cost reducing elements in a firm, and have a negative effect

2. It is the technology-push factors that increase the firm's propensity to innovate. This is evident from the positive impact of new product sales (*innsales*), product innovation strategy (*prodstr*), and continuous R&D (*rddep*), on the firm's innovation decision. It suggests that firms embedding innovation as an integral part of their organisation structure have a greater propensity to innovate.

3. The demand-pull elements such as more market share, post product development strategies, and export markets do not increase the probability of having R&D.

4. Size is a significant firm determinant to engage in innovation, (Cohen & Klepper 1996; Klette & Kortum 2002). Firm's resources are an important factor that determines their capacity to invest in R&D. The larger the firm's resource, greater is its probability of innovating. Firms with resources, (employees, innovation sales and internal R&D department) are most likely to have innovation investments. This is due to their scale advantage, and because they are able to get greater returns from research investments. Firms invest in innovation mainly to offset the firm specific resource disadvantages.

5. There is less of an incentive to invest in innovation when firms have already achieved innovation capability and efficiency. Patents, higher labor productivity, and firm's internal source of knowledge for innovation gives them the competitiveness, and enables them to effectively utilise the external technological opportunities, and hence such firms decides not to incur innovation expenditures.

6. The likelihood of innovating reduces when the spillover are greater from the market, educational and public sources, and from firm's internal sources.
7. The persistence of innovation (Raymond et al. 2006; Geroski 1997) of hi-tech firms is evident in the estimation results of the selection equation, from the feedback effects of innovation success to the innovation input decision (Janz & Peters 2002). Commercial success of a firm's innovation in the past, (sales from new products and services launched in the last 5 years) are invested back into the firm, to finance research activity, thus supporting 'success breeds success' hypothesis (Mansfield 1968). Similarly, the persistence of innovation explained by sunk cost is supported here. Firms with R&D department need more investment to build & maintain it, hence are most likely to have R&D expenses.

10.5.2 Innovation Input Equation (2)

Innovation expenditure intensity increases with firm's internal R&D organisiation, higher patent intensity, and external factors such as spillover from market sources and greater research alliance intensities (see Table 10.6). It is seen to be lower for the firms pursuing demand strategies, and government alliances. The results suggest that it is the intense research collaborations that increase hi-tech firm's internal innovation input intensity, relying on mere spillover benefits from these research and public sources do not raise their innovation input (*edpsrc* is not significant). Market source of knowledge spillovers however, are able to increase firm's innovation input. Theory suggests that small young firms are greater innovation intensity (innovation per employee). This is reflected here as well even though the variables are not significant.

Patenting has a strong positive impact on the innovation input, (*patent* is significant at 1%, in Eq. 2). From the selection equation (1) it is evident that firms with greater patent intensity has less incentive to invest in innovation expenditures, but once they decide to invest, the innovation expenditure intensity increases with patent intensity. Patents are an outcome of radical innovations, and are both time and cost consuming. Firms need resources, like skills, expertise, and knowledge, which results in greater expenditure. The firms doing innovation on a continuous, routinised basis, and organised as a department, not only has greater probability of having innovation investments but also has significantly greater innovation input intensity. This is in line with empirical results (Klomp & van Leeuwen 1999; Meeus & Oerlemans 2000; Ebersberger & Lööf 2005).

The absorptive capacity hypothesis that firms require a certain level of internal R&D to assimilate the external information on innovation especially the difficult to codify tacit information on new, complex technology, sourced from research institutes is supported here (Dosi 1988, Cohen & Levinthal 1989, 1990; Zahra & George 2002). Spillovers from these research alliances, drives firm to invest in innovation (Audretsch & Stephan 1996; Caneils & Rominj 2003). *Resaln* is positive and significant when controlling for the impacts of different knowledge spillovers (Rominj & Albaladejo 2002; Zucker et al. 1998; Belderbos et al. 2004; Tether 2002; Monjon & Waelbroeck 2003).

For hi-tech firms in Scotland, government networks (*govaln*) do not contribute to their increased innovation investment (significant at 5%). The negative effect is because the firms with low innovation inputs, form government links to access the incubation facilities, finance, research grants, skills, contacts and technological information to compensate for their lower innovation input (Kogut 1988; Das & Teng 2000). The start-up firms and nascent spin-offs in the emergence phase, lacks the necessary capital and legitimacy to exchange on the basis of market transactions, hence develop external collaboration networks to access capabilities without committing too large a share of firm resources (Baum et al. 2000; Benfratello & Sembenelli 2002; Nakamura 2003).

The customer networks (*cusaln*) do not influence the firm's innovation expenditure intensity. Customer is thought of as a co-producer and idea-generator for new product and services (Kristensson et al. 2002; Prahalad & Ramaswamy 2000; von Hippel et al. 1999). Firms seek customer links specifically for sales expansion through innovative outputs and to reduce the risk associated with market introductions of the novel, complex, and untested innovation, which necessarily does not increase its innovation input intensity (von Hippel 1988; Tether 2002).

The knowledge spillover from market sources (*mktsrc*) significantly increases the innovation intensity of firms (Caneils & Rominj 2003; Feldman 1994; Jaffe et al. 1993; Jaffe 1986; Baptista & Swann 1998). Suppliers, customers and competitors are significant sources of ideas for innovation and also the technology embodied in the product or process, sourced from them are likely to further enhance the innovation intensity of the recipient firm (Anderson & Tushman 1990; Teece 1986). The educational and public knowledge spillover (*edpsrc*), has no impact, it could be because the spillover benefits are already captured by the research alliance intensity (*resaln*). The internal source of innovation has a negative impact on both the probability to innovate and on the innovation intensity (see Table 10.6), *intsrc* is negative but not significant when controlling for other factors. It is reflected in the negative effect of the variable training on innovation input intensity of firms, (*train*) significant only in the tobit model. The explanation for this is that innovation intensive firms already have the expertise, information and highly skilled staff, hence the expenditure on training or buying external expertises is not required (Freel 2005; Rominj & Albaldejo 2002).

The demand strategy (*mktstr*) has a negative impact on the innovation input, (significant only for the tobit model). This suggests that for the innovation input stage, it is the strategies fostering product innovation that matters. This is evident from the selection equation, where strategies fostering product innovation increase the firm's innovation propensity. The firms focussing on attaining internal innovation capability does so to develop new products, process innovations and patents. They have research collaborations to achieve technological breakthrough in their R&D, and devote their resources to this, and less on the post-product development strategy and extending markets internationally. This is also evident in the fact that *export* has no effect, on the innovation input (equation 2), nor on the probability to innovate, selection equation (1).

The feedback from the performance has no impact on the innovation input even after correcting for simultaneity bias (Stoevsky 2005; Harris et al. 2001). This may be due to the fact that both innovation intensity and performance are measured in the same period. The performance lag that is essential is not accounted here. The results highlight the importance of technology-push factors. The following conclusion can be drawn:

1. It is the firm's radical innovation attempts in order to develop innovative product and patents that determine the innovation input intensity of hi-tech firms (Zucker et al. 1998). Attempts to innovate faster, deliver innovative products with specificity and differentiation that are difficult to copy, continuous R&D, and patenting are the factors that increase the innovation input. Other attempts such as increasing market share or expanding internationally does not increase it.

2. They strive to achieve this by harnessing the external opportunities and internal strengths. Both internal resources as well as factors external to the firm, contribute significantly to the firm's innovation input. Hi-tech firms face uncertainity, rapidly changing technologies, shortening product life cycles, risk of failure, all of which are driving them to increasing their innovation capability to stay competitive. This is achieved by striking a balance through a complementary mix of internal and external resources, and by utilising the technological environment to their advantage (Freel 2003; Cohen & Levinthal 1989, 1990; Dodgson 1993).

3. *Internal strengths* -by performing innovation on a continuous, long term basis, pooling resources and organising as a R&D department (Klomp & van Leeuwen 1999), and greater patent intensity, rather than pursuing strategies on expanding market share (Hadjimanolis 2000; Nelson 2000; Oerlemans et al. 1998).

4. *External opportunities* - by research networks and by taking advantage of the spillover benefit from market sources like customer, supplier and competitors so as to gain valuable information on customer demand, requirements and feedback, technological improvements, novel products and ideas introduced in the market, and information on possibilities of combining existing technologies in a novel way (Brown & Eisenhardt 1998; Anderson & Tushman 1990).

5. It highlights the requirement by the government bodies to play a greater pro-active role, in assisting with innovation capability building in hi-tech firms. Policies encouraging intermediary organisations in bringing together firms and government institutes have to be there, to achieve greater industry-government links. Government support in terms of resources, information, technology and expertise can make a difference to firms with low innovation intensity.

6. Most importantly, the research network links greatly increase the internal innovation capabilities in hi-tech firms (Zucker et al. 1998; Belderbos et al. 2004; Tether 2002; Monjon & Waelbroeck 2003). They are important to internalise the tacit technology, break-through research, know-how and information on technological trajectories that are relevant for hi-tech firms operating in an environment where technology fusion and product obsolesce are frequent.

7. Using a simultaneous framework this research supports the absorptive capacity argument that, in order to assimilate the scientific and technological information received from universities and research institutes, it is necessary to have increased innovation capability in firms, (Zahra & George 2002; Feldman 2001; Prevezer 2001) The hypothesis conjectures that cooperation with science requires higher internal R&D skills and higher innovation expenditures (Klomp & Leeuwan 2001; Zucker & Darby 1996). Firms invest in R&D to be able to achieve this and maintain a separate R&D department to maximise the possibility of research alliances on a long-term basis.

10.5.3 Innovation Output Equation

The innovation sales of hi-tech firms are determined by the demand-pull factors. Specifically, market extent of the firm, customer collaboration, and knowledge spillovers from market. The innovation output is significantly greater for exporting firms and firms with intense customer networks, (von Hippel 1988; Tether 2002), (*export*) and (*cusaln*) are significant at 1% and 10%, respectively.

Hi-tech firms that do not face obstacles to innovation are able to achieve greater innovation sales, economic factors (*ecobst*) and firm specific factors (*frmobst*) that hamper innovation, are highly negative and significant at 1%. Financial constraints like lack of funds, high cost of acquiring external finance for the purpose of new product development, the risk involved in market launch, and pay-off uncertainty from the new product development, has a strong significant negative effect on the innovation success. Moreover firm specific obstacles (lack of skilled personnel and other resources) severely affect the commercialisation of innovation.

Contrary to the findings in several of the other papers, innovation investment did not have any significant effect on the innovation output (Crepon et al. 1998). But this in line with findings of Benavente (2006) where he found that R&D did not contribute to innovative sales in Chilean firms once size, capital per worker, industry and demand-pull/technology-push is controlled for. The inverse mills ratio that corrects for selectivity is significant at 1% indicating that sample selectivity is an issue here and that it is important to take into account selection bias by using probit step (Loof et al. 2002; Janz et al. 2004). Size does not have any impact on innovation output as in Loof et. al (1996), unlike other studies using the CDM framework (Benavente 2006). This is in contrast to Cohen and Klepper's fourth stylised facts (Cohen & Klepper 1996), where small firms account for a disproportionately large share of innovation sales.

There appears to be no feedback effect from the overall firm performance to innovation output, when taking into account the joint endogeneity of innovation output and the overall sales performance, as in Klomp & Van Leeuwen (2001) and Stoevsky (2005). This may be due to the fact that performance lag is required, and is not accounted here as the past performance measures are not available.

Export status of a firm has a positive strong significant effect on innovation sales, indicating that firms that aim international markets do so with better highly competitive products and better international marketing strategy. The innovation sales are significantly increased by the collaboration with customers. The firms with greater customer alliance intensity have greater commercial success from innovations.

Research alliance also seems to have a positive effect though its impact on innovation output is not over and above its impact on innovation input. It is significant only for the tobit model, which overlooks the simultaneity for innovation output equation. This is true in the case of the government alliance intensity as well. The negative impact of government alliance intensity on innovation output is not over and above its effect on innovation input. This highlights the presence of endogeniety of the variables in the innovation input and output equation and brings into light the fact that one has to take into account the joint interdependence of innovation input and innovation output when analysing the effect of collaborations on innovation input and output. The negative relation between government networks and innovation sales reflects that of the relation between government networks and innovation input. This warrants immediate action to promote government-industry links and calls for intermediary bridging institutes that can facilitate this.

The knowledge spillovers from different sources have different impact on the innovation sales intensity. Educational and public sources has a significant negative effect on innovation output (*edpsrc* significant at 10%) at the same time internal sources (*intsrc*) and market sources (*mktsrc*) has a positive effect but are not significant, market source is significant only in tobit estimation. The firms are unable to appropriate the spillover benefits from research and government labs and other public organisations for innovation sales. Generally, the research sources do not provide information about expanding markets, potential niche markets or customer needs that are crucial for commercialisation to generate sales, but rather ideas for radical innovation and technologies and in new product development. It reflects the insufficient public-industry links that can assist in commercialisation of innovation in firms. The spillover from market does not have a significant impact in the model that takes into account the simultaneity, but is significant in the tobit model. This is because the information on customer preferences, demands, technology needs etc., are already captured by incoming rent-spillover through market transactions and customers, suppliers and competitor collaborations, which significantly increases innovation sales as discussed.

This shed light on the growing problems faced by hi-tech firms in Scotland, which is lack of internal funds allocated to near market activity and lack of government support. These affect the commercialisation of innovative products and services of hi-tech firms. Moreover, lack of necessary environment for commercialisation of research findings, such as appropriate industry organisations and other intermediary bridging institutions that can assist in marketing and sales of new products, bringing together firms with complementary resources, ideas and finance for launch in international markets.

The most important finding of the results of equation (3) is that it highlights the selectivity issue.

1. The hi-tech firms are not able to attain innovation success through innovation investments alone. Commercialisation of the innovation is major obstacle to achieving commercial success from the intense innovation in firms.

2. The hi-tech firms face many obstacles that hamper the success in achieving new product sales. Uncertainity of innovation, risk involved, failure of market launches and lack of internal resources that are crucial for innovation success are the reason they are unable to realise their innovation investments in terms of sales from product innovation. Firms that overcome these obstacles are successful in achieving commercial success. This is evident in the strong significant, negative impact of the two variables, economic factors and firm specific factors that are important obstacles to innovation.

3. Exports are the way these firms achieve international success and greater returns from innovation. Firms with export have higher innovation sales. They achieve this through developing novel products with competitive price and customer use.

4. Intense customer collaboration is vital in developing such innovative products that have greater commercialisation success and greater innovation sales (Kristensson et al. 2002; Prahalad & Ramaswamy 2000; von Hippel et al. 1999).

5. Innovation sales is not dependent on innovation input intensity when controlling for other factors like size, age, information source, innovation obstacles, export activity and networking (Benavente 2006). This may be due to the fact that the innovation expenditures are mainly targeted to patenting and pursuing other intellectual property rights, process innovation and incremental innovation for cost reduction purpose or to increase the quality of the product. Innovation sales are rather more dependent on near market aspects like product launch, market research and international markets etc. that are required for successful commercialisation of new products and services.

6. The innovation expenditures constitute R&D expenditures as well as other expenditures for near market activities such as product market launch. R&D related inputs make for a minority of innovation expenditures, varying from 15-50 percent depending on the sector, (Felder et al. 1996). In fact, in this hi-tech sample, more than 85% have R&D expenditures and for these firms the R&D expenditures constitute a massive 81.97% of their innovation expenditures. It is seen that the hi-tech firms allocate most of their innovation expenditures to radical research, purchasing licences and recruiting highly skilled technicians and less to non R&D factors. This implies that innovation intensive firms in allocating almost all of their innovation investment on R&D has less resources dedicated to near market non-R&D activities. This explains why higher innovation intensity does not improve commercialisation, innovation sales.

7. Government assistance is needed to increase commercialisation in firms to improve hold ups in successful completion of new product development arising from lack of funds, personnel and trusted intermediaries that can help with IP legal uncertainity etc are needed to launch them in the market.

10.5.4 Performance Equation

Size has strong positive significant effect on the firm performance in line with the Schumpeterian hypothesis, when controlling for patents, human capital and innovation success. Firms with local networks, has a significant positive effect on firm performance when controlling for size, innovation success and export orientation. This indicates that the embeddedness of firms in local networks or the cluster effect can increase the performance of firms (Sorenson et al. 2006; Cortright & Mayer 2002; Rominj & Albaldejo 2002; Powell et al. 2002; Niosi 2000b; Zucker et al. 1998a). This is consistent with a large literature in economic geography and industrial economics, stressing the role of agglomeration, clustering and localized learning in fostering innovation and dynamic economic growth (Krugman 1991; Audretsch 1998; Almeida & Kogut 1997; Jaffe et al. 1993; Nooteboom 1999; Maskell & Malmberg 1999). Especially, with the literature on innovative milleu which explains the importance of proximity to collaborators for higher performance (Aydalot 1986; Keeble1998; Lawson & Lorenz 1999; Camagni 1995; Malliat 1995). Human capital has a positive effect but is not significant, as in Janz et al. (2004), and so does the variable training. The estimation results for simultaneous model as well as the tobit model are very similar. Export activity does not have any direct significant effect on the returns to investment, (Lu & Beamish 2001).

As in Benavente (2006) innovation sales does not contribute to the performance of hi-tech firms. Literature supports the fact that returns from innovation requires a period of time before it results in increased performance of firms. But in this research it is evident that the performance variable measured here as returns to innovation expenditures is not dependent on the innovation sales over the last five years or patent intensity over the last five years when taking into account the joint interdependence of innovation input, innovation output and performance. The variables *(innsales)* and (*patent*) are not significant when controlling for other factors such as size, age, training, export activity, embeddedness and human capital. Moreover the firms that are engaged in R&D continuously over a long period also do not increase the performance of firms. The presence of R&D department, which is a proxy for R&D conducted continuously over a long time, has a significant negative effect.

Many inferences can be made from the estimation results of the performance equation:

1. The economic performance of hi-tech firm is mainly influenced by the scale-effect. Economies of scale and scope are very important in order to achieve economic success for the survival and existence, in an environment of technological uncertainty, complexity, pace and scope of rapid change and intense competition in global markets.

2. Innovation sales in the past five years does not directly affect the current performance of hi-tech firms but has an indirect effect on it through the propensity to innovate. Innovation sales significantly increase their propensity to innovate as is evident in the selection equation.

3. Similarly the innovation output in terms of patent intensity in the past five years does not directly increase the current performance of innovation intensive hi-tech firms, but can indirectly increase it through innovation expenditures. The patent intensity significantly increases the innovative input intensity of these firms as seen in Eq (2).

4. The fact that innovation is carried out on a long term, continuous basis and organised as a department does not have a direct positive impact on current performance nor on innovation sales. It implies that innovation effort on a long term and continuous process is less beneficial for the economic success in hi-tech firms, rather it is more important for the innovation input-side by increasing its propensity to innovate and also to increase its innovation intensity as is evident in equation (1) and (2). The significant negative impact may be due to the fact that performance is measured here as sales returns to innovation expenditure, hence when the innovation expenditure increases, the returns to innovation expenditure tends to be smaller. In this scenario, firms need greater investment to build and maintain R&D department, hence the firm's returns (ratio of sales to innovation expenditure) from it tend to be less.

5. Even though innovation does not have a direct positive impact on the economic success, it has a significant indirect effect through size in terms of scale and scope advantage. What scale effect actually does is the accumulation of internal resources and capabilities and stock of knowledge, technology expertise and innovative products and process that strengthens the competitiveness of the firm in terms of creative accumulation as opposed to creative destruction (Schumpeter). Hi-tech firms have to constantly build up its absorption capacity in order to assimilate, apply and use the external resources to complement its own strengths. All this is not possible without an aggressive innovation strategy, high innovation input intensity and embedding in innovation networks. Thus the innovativeness of hi- tech firms is crucial for its increased performance in the long run, for survival and growth.

6. A vast majority of hi-tech firms are SME-sized who seldom possess all the resources required to be successful within their boundaries. These firms internalise and complement the internal resources by embedding themselves in local innovation networks and pursuing innovation strategies, by collaborating on innovation (Rominj & Albaldejo 2002), and taking advantage of the local knowledge spillover benefits that are available from different elements in hi-tech clusters (Zucker et al. 1998a; Feldman 2000, 2001; Niosi & Bas 2001; Levin et al. 2001; Audretsch & Stephan 1996; Almeida & Kogut 1997; 1995; Jaffe et al. 1993). Access to local venture capital and finance is another key factor as they provide the investment capital, entrepreneurial and managerial know-how necessary for commercial success (Gertler & Levitte 2005; Zucker et al.; 1998b; Niosi, 2000a, b; Cooke 2001b; Powell et al. 2002). This explains why embeddeddness in local network is important for hi-tech firm performance.

10.5.5 Comparison of the Estimation Results- I3SLS versus Tobit

The results from the tobit model that estimates one equation at a time, involving only the innovative sample, and ignoring the endogeniety of some of the variables, are different in some cases, compared to the results from the simultaneous model. The different impact of the external opportunities on the different innovation stages in hi-tech firms is captured correctly, only when different links in the innovation process is estimated jointly as a system, correcting for the simultaneity bias, where all the information on the variables in all three equations are taken into consideration, as in a simultaneous system estimation.

i. It is seen that the market source of knowledge spillover (*mktsrc*) significantly increases the innovation expenditure intensity of the hi-tech firms when correcting for the simultaneity bias in I3SLS etimations, (see Table 10.6). Whereas (*mktsrc*) has a positive and significant impact on the innovation sales intensity, in the Tobit estimation that ignores the endogeniety problem (see Table 10.7). Thus it can be concluded that the market source of knowledge spillovers have a positive impact on the firm's innovation input, over and above its positive impact on the firm's innovation output, when estimated jointly as a system.

ii. Similar results are obtained for the research networks also. The positive and significant impact of (*resaln*) on innovation output in the tobit model disappears in I3SLS model. At the same time it is seen to have a significant positive impact on the innovation input of hi-tech firms, when estimated jointly as a system in I3SLS. The research networks of hi-tech firms contribute greatly to its innovation input intensity, over and above the contribution to its innovation output intensity.

iii. It is evident that network effects on the innovation, is significant only when correcting for the endogeniety, in the simultaneous model. The positive influence of customer networks on the innovation output becomes significant in the I3SLS estimation. The positive impact of research networks, and the negative effect of government networks on the innovation input, becomes significant only in the simultaneous model that corrects for the simultaneity bias, and not in tobit model.

iv. Similarly the incoming knowledge spillover effects are not captured properly in the tobit model. The negative significant impact of spillover from education/public sources on the innovation input, and the positive significant effect of spillover from market sources are captured only in the I3SLS model.

10.6 Conclusion

This chapter gave a detailed account of the applied econometric model developed in this research on high technology firm networks, innovation and performance. It set forth to unfold several aspects in the complex innovation process in firms. Specifically, it estimated the impact of innovation investment on innovation output and the impact of innovation output on firm performance in manufacturing and service industries, using the simultaneous framework. It highlights that the interdependence in the link between innovation, networks and performance in firms cannot be explained by least square estimations, it is necessary to estimate the different links in simultaneously and also by solving for the sample selection problem. Its contributions are on many dimensions. The selection of the variables in the model, model specification, estimation techniques used in solving for sample selection bias and simultaneity bias, and comparison of simultaneous model with that of the tobit model have all been very important in analysing the high technology performance, networks and innovation in firms. The data set provided very useful information on all stages of the innovation process in firms. It captured the spillover benefits from three different sources, and the network intensity with research, customers and government bodies, which is important in determining this link between innovation input, innovation output and performance. The results highlight the selectivity issue.

Many stylised facts on the link between firm performance and innovation were tested here. Many important issues and inferences were highlighted in this chapter. It is of paramount importance to achieve commercial success for the innovation intensive firms in Scotland. The gains from the commercial success are injected back into the innovation process to increase their innovation capability. International strategies and exports are crucial factors that can achieve this. Intense customer collaboration enables firms to develop innovative novel products that are competitive in international markets and thus increase innovation sales. The hi-tech firms in Scotland are unable to achieve commercial success from their innovation. There are many challenges that Scottish firms face like lack of firm specific resources, necessary funds for non-R&D activities that can push the successful completion and launch. It warrants major role of government bodies in creating an environment for commercialisation of research findings by means of greater industry-government links, bridging and intermediary agencies that can bring together organisations with complementary capabilities to increase the new product sales and legal uncertainties involved in IP when firms collaborate on innovation. Firms collaborates with research institutes and universities to increase its internal innovation capability. Government has to have a proactive role in increasing firm’s innovation capability. Firms have to strive and achieve right balance between R&D and non-R&D activities by dedicating a share of its innovation expenditures/resources in post-product development, near-market aspects etc.

Hi-tech firms with aggressive innovation strategies and international markets still find it very important to be embedded in local networks which in turn increase their performance (Gertler & Levitte 2005; Zucker et al. 1998a). In this way this research supports the fundamental ideas of the Innovative Milleu concept (Aydalot 1986; Keeble1998; Lawson & Lorenz 1999; Camagni 1995; Malliat 1995), (see chapter1 section 1.4), that spatial concentration enables face-to-face networking, common labour markets and diffusion of knowledge, in particular the ‘tacit’ knowledge that are difficult to codify (Maskell et al. 1998; Nooteboom 19; Lawson & Lorenz 1999). All of this are indispensable to knowledge intensive, hi-tech firms, in commercialisation efforts (Cortright & Mayer 2002), developing basic research (Niosi 2000b) and innovation capability (Cooke 2002a), and in its competitiveness (Powell et al. 2002; Audretsch & Feldman 1996; Almeida & Kogut 1997; 1995; Jaffe et al. 1993; Dosi 1988).

Like most previous researchers, the likelihood of having innovation expenditures rises with firm size, but after controlling for networks, innovation input intensity is not influenced by firm size (Loof & Heshmati 2002). This is true for both simultaneous and tobit model. Larger firms have higher propensity to invest in innovation, and have higher performance, (returns to innovation investment). These findings are familiar to other countries, and confirm the Schumpeterian view of innovation as an activity undertaken by larger monopolistic firms. However, size does not increase the innovation intensity, as size does not have a positive effect on innovation expenditure nor on innovation sales intensity. Firms with more patent intensity, has less incentive to invest in innovation, but once they decide to invest, the innovation expenditure increases with patent intensity. Firms doing continuous innovation not only has greater probability of having innovation investments but also has more innovation input intensity. This is in line with other empirical results (Klomp & van Leeuwen 1999; Meeus & Oerlemans 2000; Ebersberger & Lööf 2005).

Table 10.5 SELECTION EQUATION (1)			
Variable	*Coeff.*	*t*	*P value*
Age	-0.0115	-0.078	.9377
Size	0.022**	1.956	.0505
Innovation Sales Intensity	0.391*	1.793	.0730
Labour Productivity	-0.011**	-2.422	.0154
Human Capital	-0.002	-0.350	.7262
Patent Intensity	-0.494*	-1.795	.0727
Export Status	0.013	0.032	.9747
R&D Department	1.028**	2.125	.0336
Internal Information Source	-0.173	-1.252	.2105
Market Source	-0.202	-0.885	.3763
Education / Public Source	-0.176	-1.418	.1563
Productivity Strategy	-0.238	-1.568	.1169
Product Innovation Strategy	0.273*	1.646	.0998
Market Share Strategy	-0.009	-0.067	.9468
Economic Obstacles	0.161	1.232	.2179
Firm Specific Obstacles	0.579***	3.328	.0009
Constant	0.666	0.568	.5704
Observations	137		
Log Likelihood -34.15		Chi-squared	38.29***

TABLE 10.6	INNOVATION INPUT EQUATION (2)						
	I3SLS Iterative 3 Stage Least Square				TOBIT		
Variable	*Coeff.*	*t*	*P value*		*Coeff.*	*t*	*P value*
Age	-2.962	-1.604	.1086		-1.861	-0.834	.4042
Size	-.75e-02	-0.510	.6100		-.42e-03	-0.785	.4324
Performance	.99e-03	0.234	.8151		.20e-03	0.311	.7557
Human Capital	0.097	1.159	.2464		0.0615	0.657	.5110
Patent Intensity	11.13***	2.858	.0043		25.37***	4.703	.0000
Export Status	-.30e-02	-0.106	.9159		3.904	0.684	.4939
R&D Department	25.21***	3.405	.0007		18.21***	2.792	.0052
Training	-9.108	-1.612	.1070		-11.913*	-1.844	.0650
Internal source	-1.75	-1.041	.2979		-3.795	-1.563	.1180
Market Source	4.75**	2.169	.0301		0.120	.0380	.9696
Education/Public source	-0.543	-0.351	.7258		0.344	.1567	.8754
Productivity Strategy	-0.168	-0.102	.9191		-0.155	-0.078	-.9375
Product innovation strategy	0.561	0.265	.7911		1.046	.3923	.6947
Market Share Strategy	-2.84	-1.565	.1175		-5.927**	-2.668	.0076
Customer alliance intensity	-0.145	-0.149	.8812		1.341	0.921	.3570
Research alliance intensity	0.017*	1.901	.0573		-1.486	-0.309	.7572
Government alliance int.	-0.017**	-1.991	.0465		-9.194	-1.568	.1169
IMR	-.66e-02	-0.377	.7060		3.923	0.271	.7866
Constant	13.63	1.076	.2820		53.07*	1.918	.0551
Log Likelihood	-701.47				-471.42		
Observation	151				101		

TABLE 10.7 INNOVATION OUTPUT EQUATION (3)							
	I3SLS Iterative 3 Stage Least Square				TOBIT		
Variable	*Coeff.*	*t*	*P value*		*Coeff.*	*t*	*P value*
Age	.67e-02	0.060	.9526		0.027	0.229	.8188
Size	.34e-03	0.186	.8526		.34e-03	1.210	.2263
Innovation Expenditure Int.	-.58e-02	-0.380	.7038		-23e-02	-0.499	.6178
Performance	.68e-04	0.133	.8942		-.96e-05	-0.262	.7934
Export Status	1.00***	575.1	.0000		0.786**	2.546	.0109
R&D Department	-0.235	-0.225	.8218		-0.825**	-2.145	.0320
Local Embededdness	0.503	0.771	.4405		0.032	0.107	.9144
Internal source	0.117	0.981	.3264		0.159	1.128	.2594
Market Source	0.057	0.353	.7240		0.3301*	1.896	.0579
Education/Public source	-0.176*	-1.772	.0763		0.0391	0.332	.7400
Economic Obstacles	-0.396 ***	-4.354	.0000		0.081	0.601	.5480
Firms Specific Obstacles	-0.599 ***	-6.572	.0000		-0.418***	-3.083	.0020
Customer alliance intensity	0.1006*	1.748	.0805		0.078	1.020	.3079
Research alliance intensity	.58e-03	0.967	.3337		0.479*	1.871	.0613
Government alliance int.	-.24e-03	-0.407	.6839		-0.429	-1.342	.1793
IMR	1.001***	688.55	.0000		-2.78***	-2.995	.0027
Constant	3.14***	5.422	.0000		-0.240	-0.200	.8413
Log Likelihood	-279.49				-162.08		
Observation	151				101		

TABLE 10.8 PERFORMANCE EQUATION (4)							
	I3SLS Iterative 3 Stage Least Square				TOBIT		
Variable	*Coeff.*	*t*	*P value*		*Coeff.*	*t*	*P value*
Age	-5.97	-0.027	.9788		-40.45	-0.135	.8923
Size	3.43***	6.066	.0000		3.31***	4.925	.0000
Innov. Sales Intensity	-0.103	-0.035	.9717		141.79	0.520	.6024
Human Capital	8.040	0.890	.3735		12.980	1.066	.2866
Patent Intensity	168.14	0.355	.7225		52.77	0.066	.9475
Export Status	-0.069	-0.016	.9872		896.99	1.156	.2475
R&D Department	-1364**	-2.23	.0254		-2271**	-2.719	.0065
Training	360.43	0.533	.5943		700.90	0.786	.4316
Local Embededdness	1187**	2.035	.0418		1502**	2.008	.0447
IMR	0.925	0.839	.4015		-1000.5	-0.604	.5455
Constant	-1077	-0.731	.4645		-1915	-0.959	.3374
Log Likelihood	-1433.06				-1067.62		
Observation	151				119		

*** significant at 1% ** significant at 5% * significant at 10%

Chapter 11 Conclusions

11.1 Introduction to Principal Contribution of the Research

This thesis has aimed to provide an in-depth understanding of hi-tech firms. Under this broad research objective it has explored a number of research aspects in the context of an empirical analysis of Scottish hi-tech firms. The key areas are: the dynamic innovation process in hi-tech firms; their economic performance; the hi-tech firm networks; and their extent of internationalisation and embeddeddness. Most importantly, by structural equations modelling, it explains the relationship between networks, innovation and performance, by establishing empirically a link between the innovation input, the innovation output, and performance, based on the empirical knowledge production function model. This is analysed in a simultaneous framework that solves for both sample selection bias and simultaneity bias, in an encompassing model (see Chapter 10).

The main finding is that the dynamic innovation process in firms and its impact on performance need to be analysed as a system, in order to capture the interactions between different innovation stages, networks and performance. The knowledge production function should be estimated not as a single equation but as a system of equations, due to the complex process linking new ideas, to innovation output, to performance (Klomp & van Leeuwen 2001; Loof & Heshmati 2002). The relative importance of the firm specific and the external demand-pull, technology-push variables, diverge from the estimated impacts of the single-equation approach, when taking into account the simultaneous nature of the variables. Further, sample selection bias is an issue (Janz et al. 2004). Since not all firms are engaged in innovative activities, any analysis that includes only innovating firms must lead to selection bias and this has to be corrected (Ebersberger & Loof 2005).

In the modern world, hi-tech products are inherently global. The evidence suggests that hi-tech firms are export intensive. Such firms have global products which face rapidly changing technologies, global competition, shortening product life cycles, risk of failure, all of which drive them to increase their innovation capability, in Schumpeterian fashion to stay competitive. The innovation input intensity is determined by firm’s radical innovation efforts, like developing innovative product and patents (Zucker et al. 1998). The technology-push factors are most important; other attempts such as increasing market share or expanding internationally do not increase it. They achieve this by striking a balance, through a complementary mix of internal and external resources, and by taking advantage of the technological environment (Freel 2003; Cohen & Levinthal 1989, 1990).

The firms harness the internal strength by performing continuous R&D that is organised as a department, and engaging in intense patenting (Klomp & van Leeuwen 1999). The external opportunities are harnessed by intense research networks, which are important to internalising the tacit technology, and break-through research know-how on technological trajectories (Belderbos et al. 2004; Zahra & George 2002). Innovation input is also raised by spillover benefit from market sources (Caneils & Rominj 2003), provideing firms with valuable information on customer demand, feedback, technological improvements, novel products/ideas introduced, and possibilities of novel combination of existing technologies.

The hi-tech firms pursue intense new product development. However, they are unable to attain innovation success through innovation investments alone (see Chapter 10). Commercialisation of the innovation is a major obstacle to achieving innovation success. Innovation sales are not dependent on innovation input intensity when controlling for other factors (Benavente 2006). Many firms doing new product innovation have zero expenditure. Innovation sale is mainly determined by the demand-pull factors, specifically, exporting, market expansion strategies, intense customer collaboration and knowledge spillovers from market. This applies to their export performance as well (see Chapter 8).

Innovation sales and export sales are rather more dependent on near market aspects like product launch, market research and international marketing capabilities and knowledge. Knowledge inputs for technological commercialisation have to be accessed from external sources, as strictly in-house development of such complementary knowledge is often not economically feasible. It is vital to integrate both internal and external sources to achieve innovation success. Lack of internal resources and capabilities severely affect the firm’s innovation success. Firms that overcome these obstacles are successful in achieving commercial success, and have greater export intensity. This highlights the growing problems faced by hi-tech firms in Scotland, which is the lack of internal funds allocated to near market activity and lack of external government support.

Other findings are that hi-tech firms with aggressive innovation strategies and international markets still find it vital to be embedded in local networks (Sorenson et al. 2006; Cortright & Mayer 2002), which in turn raises its performance, confirming that networks are an important determinant of hi-tech innovation and performance. However, the relative impact of customer, research and government networks on innovation input, innovation output and economic performance are different. Government links greatly influence exports performance, but does not contribute to their increased innovation investment or innovation success. The customer networks are vital for achieving outcomes like innovation sales and exports, and not innovation input (Kristensson et al. 2002; von Hippel et al. 1999). It is the research network that can greatly increase their innovation input intensities.

The innovation output (patents and innovation sales) does not influence the performance (returns to investment), but positively impacts upon both export performance and the export propensity, after controlling for size, demand-pull, and technology-push variables. The firms with greater patent intensity, have less incentive to invest in innovation expenditures, but once they decide to invest, the innovation expenditure intensity increases with patent intensity. The larger the firm's resources, in terms of employees (size), innovation sales and R&D department, the greater are their export intensity, and the most likely they are to have innovation investments. In the case of export performance, above a certain size threshold, size no longer plays a significant role (Hollenstein 2005).

Size positively impacts upon performance, but does not influence the innovation intensities, when the innovation input, innovation output and performance are jointly estimated in a simultaneous framework. However, when the relation between size and innovation are analysed by means of regression of a cubic function permitting the identification of inflection points and nonmonotonicity in the relation, a non-linear relationship is confirmed using robust estimations (see Chapter 7). The result encompasses both the notion of an optimal small firm size and also the Schumpterian hypothesis (Schumpeter 1942; Kohn & Scott 1982). However, it supports Shumpeterian hypothesis only at very high scales. At lower scales there is an optimal size, supporting small size advantage in innovation.

This research was field work based and used primary data gathered by means of structured questionnaires on a cross-section of hi-tech firms. The main contributions are:

- A new, unique and in-depth database on hi-tech firms across five sectors in Scotland, was constructed, that involved quantitative and qualitative data on the conduct within hi-tech firms. It is successful in that: it represented the 'hi-tech population' well; it captured extensive information on hi-tech firms that did not exist before, and enables future advanced and comparative analysis (sector or economy-wise).
- The database allowed detailed cross-sectional analysis of several important topics of significant interest to researchers in policy, academia and industry. This is one of the few studies on substantial part of service and manufacturing sectors of high technology.

- This research focussed on investigating the dynamics of innovation and performance. It incorporated the features of time-series dimensions to a certain extent, using the survey instrument to capture it (see Chapter 5).
- The complex innovation process in hi-tech firms can be disintegrated into 3 stages:
    i. *Innovation Input Stage* (innovation decision, expenditures etc.)
    ii. *Innovation Output Stage* (patents filed and granted, new products introduced and in the pipeline, sales from new products)
    iii. *Innovation Throughput Stage* (innovation strategies, networks).

  This enabled a broader understanding of innovative performance trajectory, right from idea conception, to the introduction of an invention in market, and returns from innovations. It highlighted the significance of internal, external resources for innovation and performance. It contributes significantly to the firm-level innovation literature.
- The firms were further characterised on a spectrum of innovativeness, from highly innovative, to innovative, and non-innovative (see Chapter 6), in terms of:
    - *Count of innovations* (number of new products and patents),
    - *Value of innovations* (innovation sales and expenditures),
    - *Innovation intensities* (innovations deflated by size measures).

  The rich data on different innovation dimensions allowed a more comprehensive consideration of the hypothesis tested, in achieving robust results and positive conclusions.
- This thesis thus addresses key issues in the measurement of the innovation process in firms (Brouwer & Kleinknecht 1996, 1997).

11.2 Summary of Main Findings

This section summarises the key research conclusions and contributions by reference to the main analytical parts of this thesis, (chapters 6 to 10), as these are the parts of the thesis that most embody them. **Chapter 4** set the scene for this research by presenting the evolution, strengths and weakness of Scotland's hi-tech sectors in the light of the policy framework.

Chapter 6 builds up a picture of the typical hi-tech firm in the sample. It contributes to the literature by presenting a preliminary analysis of the data in the cross-sectional dimension, by exploring the main characteristic features of the hi-tech firms in the sample. Further, it compared the sample with the 'Scotland population', (all sectors in Scotland), which consolidated the picture of prominence of high technology in the Scottish economy.
The main findings are as follows:

The sample constitutes a fair and equal representation of the firms in the five Scottish hi-tech sectors. The sector-wise distribution of the sample is representative of the ‘hi-tech population’. The firms are predominantly SMEs (94%), with the predominant firm type being the micro-firm (51%). This is comparable to that of the ‘Scotland population', where the SMEs constituted 99%. However, the size-distribution of firms varies from that of the Scotland population. The sample has a lower proportion of micro firms, unlike the Scotland population (92%). The characteristics of the firms varied across size group. The size is positively correlated to the age, turnover and labour productivity.

Hi-tech firms display high R&D intensity. It is very high compared to industry sectors such as telecom, office machinery & computers, electrical machinery & apparatus, computer services and aerospace, in Scotland and in the UK, in 2003. However, it is below pharmaceuticals. 80% of the hi-tech firms had innovation expenditures, and 69% had R&D expenditures. The composition of the workforce also indicated its high innovation input intensity, as the technicians & scientists comprised about half of the total workforce. The new product development in the sample is also intense. Thus 92% undertook new product development. 82% had new products on the market and 71.5% had revenue from them.

A vast majority of firms are not involved in patenting. However, for the patenting firms their patent intensity is very high. The composition of the sample, could explain this low participation in patent activity (only 30% participated). Reasons could be: the presence of embedded software firms and those in the software sector in the composition of the sample, for whom patents are irrelevant (though not copyright), and also the cost involved in patenting, which meant it was not possible, economically to justify patenting for many small and relatively new firms (Kleinknecht & Reijnen 1991; Kleinknecht 2000). However, the patents per £million R&D expenditure, revealed the innovation-intense character of the hi-tech sector. Hi-tech firm is export-intensive, competing in distant global markets. Exports accounted for about three quarters of the firm’s total sales. The sample had a greater share of exports in the overseas markets, compared to the Scotland population.

Chapter 7 dealt with the performance of hi-tech firms. It involved empirical examination of the growth and innovative performance heterogeneity, across size. Firstly, the relation between size and innovation are analysed by means of regression of a cubic function permitting the identification of inflection points and nonmonotonicity in the relationship (see Chapter 7, section 7.2). The main conclusions are that in the case of hi-tech firms, the non-linear relation between firm size and innovation is confirmed by using robust estimation.

The result encompasses both the notion of an optimal small firm size and also the Schumpterian hypothesis. However, it supports the Shumpeterian hypothesis only at very high scales. At lower scales there is an optimal size, supporting small size advantage in innovation. Small firms are sometimes growing on to achieve Shumpeterian size. Thus one has a kind of local equilibrium, in which small firms seem to have an innovation advantage; but aggressive, high growth firms can jump to higher innovation intensities at much larger scale, and enjoy large benefits of increasing returns. Once the higher growth firms have achieved the scale necessary for the Schumpeterian effect to take hold, they start to generate effects analysed in endogenous growth models, for which expansion, innovation, then further expansion are mutually reinforcing (Reid 1989).

This relationship is observed for both innovation input and innovation output measures. These results are validated, by using different measures on the innovation volume, innovation counts, and innovation intensities. The relationship holds for all, except for new product launch intensity and new products in the pipeline intensity. The maximum and minimum turning points observed for the estimations using different innovation measures are similar. Innovation is seen to increase with firm size until it reaches a maximum level, at employment size ranging from 900 to 980, depending on the innovation measure used. After this size the innovation of the hi-tech firm is seen to fall as firm size increases until it reaches a minimum innovation level at large firm size (observed around 2000 employees for innovation count measures, and close to 4000 for innovation volume and all innovation intensities). Beyond this size, innovation increases for the largest firms only.

The empirical testing of Gibrat’s Law of Proportionate Effect on the hi-tech firms, performed to investigate the growth performance of firms, relative to their size, revealed robust results, confirming that Gibrat’s Law is refuted for the hi-tech sample (see Chapter 7, section 7.3.1). The small firms have higher growth rates compared to large firms. The employment, turnover and labour productivity growth are all higher for small firms. Robust results are obtained by using 3 different scale measures, and by using growth rates for 4 different periods, for each of the 3 scales. It is seen that the equilibrium state is reached for small sized firms (Reid 2007). It is to be noted that the long-run equilibrium employment sizes implied by this version of the model are quite small, certainly much smaller than the sizes at which the optimal size for innovation or the Schumpeterian effect takes over.

Chapter 8 dealt with a detailed investigation of the international orientation of firms, where it analysed firms, international alliances and their export performance.

In the preliminary analysis of this chapter (see Sections 8.2.2, 8.4, 8.5), three export measures were used: export participation, exports intensity, and market extent. The robust measures facilitated the understanding of the hi-tech export performance to a great extent. Building on this, the multivariate Tobit estimation, with correction for sample selection, estimated econometrically the contributions of the independent variables to the firm's export decision, and also the explanatory power of these variables for export performance (see Section 8.6). It contributed to the literature on export performances at the firm level and has policy implications. It can guide policy by devising strategies in the light of the findings, to raise the internationalisations in SMEs.

The findings are that hi-tech firms show a high degree of internationalisation, in terms of exports, and global networks. A very high proportion of firms have international alliances. 77% collaborate outside Europe, and 70% have alliance in Europe. The intense collaborations of internationally networked firms, as compared to the domestically networked firms, are explained by their horizontal networks with research organisations and competitors; vertical networks with supplier and customers; and their innovation output (product innovation & patents). Size is not a factor in explaining the intense networking by internationally focussed firms (see Section 8.2.1). However, size has a positive impact on export intensity but not on their export propensity, in the results of the Tobit estimation. Thus the impact of size on the export decision is different to the impact on export intensity. The export intensity increases with size up to a point, but after reaching this threshold, size no longer plays a significant role, suggesting a non-linear relation (Lefebvre et al. 1998).

The final stage of the innovation process has a profound impact on export performance. Firms with innovation output have significantly higher probability of exporting and also greater export intensity. The commercialisation of the innovations is important. It is crucial for hi-tech firms to have novel, better and cheaper products faster, and the know-how to compete in overseas markets. Hi-tech firms do this by patents and by the marketing of innovative products. It is a prerequisite in the case of hi-tech firms to have the efficiency and capability to be competitive in global markets. In particular the experience and knowledge of the entrepreneur with regards to overseas markets and international products, is vital (Coviello & Munro 1995). Intense government networks providing access to complimentary resources necessary to achieve greater exports, are also important.

Technology push factors do not increase export performance: rather it is the demand-pull factors that increase it (see section 8.6.1). Investing in innovation expenditure, or pursuing strategies on technology intensive products alone do not result in exports. It is the organisational strategies focused on expanding and capturing new markets, commercially viable products, and the know-how to achieve this that increase export performance. Firms in the product development stages devote all their resources towards developing novel, efficient and innovative products, at low cost. Such firms have less resource dedicated to post-product development strategies, like international marketing capabilities. Firm specific resources are important for increasing their export intensity (Acs et al. 1997; Fujita 1995).

Chapter 9 examined the dependence of the hi-tech firms on their external technological and market elements, by analysing their networks, across seven different collaborator types, as well as across five different locations of their collaborators. This work is at an in depth level, not done previously, and the robust estimation results contribute to the SME-oriented networks literatures. It can be concluded that the great majority of hi-tech firms networked with multiple collaborators in various locations, emphasising the importance that hi-tech firms attach to strategic alliances (Kaufmann & Tödtling 2001; Baum et al. 2000). However, the network intensity differs across firm size. The SMEs have greater network intensity compared to large firms (Almeida & Kogut 1997, Love & Roper 1999; Rogers 1998). This result holds for all seven network types (see Section 9.4). The spatial network pattern of data, show that proximity to collaborators is not important to maintaining close contacts (see Section 9.3.3). The proximity does not increase the intensity of networks, in terms of greater contact frequency, except in the case of competitor alliances. Hi-tech firms are less embedded in terms of sales and purchases, ie., global sales and purchases (see Section 9.5.1). But when it comes to recruitment and entrepreneur's background, they are less global, exhibiting more embeddeddness than other aspects of hi-tech firm's operations.

The form of network across the customer, supplier, competitor, research, government, trade and finance networks revealed interesting insights. Hi-tech firms greatly value their vertical linkages (customer, supplier). It is very intense in terms of both alliance intensity and contact frequency. These alliances mainly deal with product development, product testing, the production process and cost reduction, all of which require close contact and strong linkages, due to the tacit nature of the know-how about complex technology. The hi-tech firm's high contact intensity in supplier and customer links is not influenced by proximity.

Horizontal alliances are less intense compared to vertical alliances. Firms display frequent contacts in research, government and finance networks. Firms nurture these links mainly for resource sharing, and hence require frequent contact. The research and government lab facilities, scarce technical and human resources, and grants and finances, are crucial to their survival. However, the incidence of the networks with competitor, are less frequent, as its purpose is to seek information, ideas on technology, overseas and niche markets, which require mostly a one-time contact or so. However, in the case of competitor alliances distance does matter, proximity to competitor collaborators improves their contacts.

The hi-tech research networks are intense, but not as intense as customer or supplier networks. However, all research alliances have the same intensity, irrespective of the location of research collaborators. It is vital to have intense research networks and to strike the right balance by having both global as well as local networks, to increase their innovation capability, and to be at the forefront of cutting-edge technology. Very few firms have finance alliance that are distant, but these alliances are more intense, and more firms have government networks in Scotland and the UK, compared to overseas networks. However, proximity does not increase the contacts in finance or government networks.

Chapter 10 dealt with the estimation of the simultaneous 2-stage, four equations model, to explain the link between the different innovation stages and performance. The results highlight the simultaneity and selectivity issue. Due to interdependence in the link between innovation, networks and performance in firms, it cannot be satisfactorily estimated by the method of least squares. It is necessary to estimate the different links simultaneously and also to solve for sample selection problems. The contributions of this modelling are on many dimensions. The variables, model specification, the estimation techniques used in solving for sample selection and simultaneity biases, and comparison of simultaneous model with that of the tobit model have all been important in the analysis.

The results highlight that hi-tech firms with aggressive innovation strategies and overseas markets still find it important to be embedded in local networks, which in turn increase performance. In this way this research supports the fundamental ideas of Innovative Milleu concept that spatial concentration facilitates face-to-face networking, stimulates common labour markets and encourage diffusion of knowledge, in particular the difficult to codify tacit knowledge (Aydalot 1986; Keeble 1998; Camagni 1995; Malliat 1995).

Larger firms have a higher probability of having innovation expenditures, and performance. These findings confirm the Schumpeterian view of innovation as an activity undertaken by larger monopolistic firms (Schumpeter 1942). However, size does not increase firm’s innovation intensity, as size does not increase its innovation expenditure nor innovation sales when controlling for technology-push, and market-pull variables (Loof et. al 1996).

This research supports the absorptive capacity argument (Cohen & Levinthal 1989, 1990; Zahra & George 2002; Monjon & Waelbroeck 2003) that, research networks can raise the innovation intensity of firms, i.e., in order to assimilate the scientific and technological information received from universities and research institutes, it is necessary to have increased innovation capability. Continuous R&D that is organised as a department increases both the probability of having innovation input and their innovation intensity. The firms with higher patent intensity have less incentive to invest in innovations, but once they decide to invest, the innovation expenditure intensity increases with patent intensity.

It is of paramount importance to achieve commercial success for the innovation intensive firms in Scotland. The gains from their commercial success are injected back into the innovation process to increase their innovation capability. Innovation sales do not directly affect the current performance, but have an indirect effect through the firm's propensity to innovate. Intense customer collaboration enables them to launch novel products in international markets (Belderbos et al. 2004; von Hippel 1988; Tether 2002). However, the hi-tech firms in Scotland are unable to achieve commercial success from their innovation investments alone. There are many challenges: lack of firm specific resources, necessary funds for non-R&D activities, and government support to help them complete the product development and in launching. Integration of internal and external resources is important.

It warrants a greater role of government bodies in creating an environment for commercialisation of research by means of greater industry-government links. Appropriate industry organisations and other intermediary bridging institutions that can assist in marketing and sales of new products, bringing together firms with complementary resources, ideas and finance for launch in international markets, are needed. The firms have to achieve the right balance between R&D and non-R&D activities, by dedicating a share of their innovation resources to post-product development and near-market aspects. International strategies and export capabilities are vital for innovation success.

11.3 Implications of the Research for Further Work

One of the important implications of this research is with respect to the time lag of the key innovation and performance variables. Firstly, the econometric model would benefit if a lag between the innovation expenditures and the performance in hi-tech firms were allowed. In Chapter 10, the innovation input, and the performance (sales returns to innovation investment) are measured in the same year. There appears to be no feedback effect from the overall firm performance to innovation input, in the innovation input equation (2), when taking into account the joint endogeneity of innovation variables and performance. This may be because a performance lag is required, and is unaccounted for here as the past performance measures are not available. Secondly, as current rather than past performance is used, it does not capture the feedback effect from the overall performance to innovation sales in the innovation output equation (3), of the model.

In this research a conscious effort has been made to overcome the drawback of innovation indicators based on counts. Be it patent or new product counts, the drawback is that all innovations are valued equally. The share of sales from product/ service innovations used to measure innovation output, offers a solution here. Still, there are two problems with this indicator: Firstly, sales are related to a time period and the choice of the time period is somewhat arbitrary; secondly, the share of sales with new products may have risen because of a general shortening of product life cycles. In order to overcome these two shortcomings, the sales from new products over the period of 5 years (1999-2003) are used in the performance equation (4) and to capture the knowledge production function (innovation output equation). However, to capture the knowledge production function, past innovation expenditure would have been a better measure than the current innovation expenditure (a proxy for the innovation input), in the innovation output equation (3). Specifically, what is needed is past and current performance and innovation measures. This would require further primary source data collection, and the research budget to undertake it.

Further research could estimate a similar model, investigating the innovation-performance casual relation using employment and sales performance, growth performance, and labour productivity performance. Lack of data on the profitability performance measure prohibited the analysis of the simultaneous model as well as the test of the Gibrat's Law. The Gibrat's Law was tested only for a small period (ranging from 1999 to 2003), due to lack of the performance data outside this range for the three scales used. Longitudinal data on the scale measures has to be gathered for the testing over the life cycle of the hi-tech firm.

Three network variables (customer, research and government) were used to unravel the hi-tech network effect on innovation and performance. The econometric models on export in Chapter 8 and simultaneous model in Chapter 10 could be re-estimated using supplier, competitor, trade and finance networks to understand those impacts, in further analysis. Finally, the various hypotheses on performance, innovation, growth, exports and internationalisation in firms could be extended by gathering data on firms in other sectors, countries etc. for comparative purpose.

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APPENDIX 1 GUIDELINES

Solutions and Recommendations based on the Pilot Survey

1. Specify the return date in the covering letter.

2. The return dates should be two weeks from the day of dispatch.

3. SAE (Self Addressed Envelope) should be printed and addressed to CRIEFF address (name not necessary).

Update the questionnaire

4. Insert a 4-digit identification code.

5. Id. No. will be XYYY, X stands for the five sectors and Y stands for number in from 1 to 836.

6. In Section A Q1, The figures on Investment instead of Exports, as exports are available in Section D.

7. In Section D Q3, Column five has to be changed to OTHER instead of ANOTHER FIRM.

8. Note the use of R&D Expenditure in Section B Q4, as a check on Innovation Expenditure in Section E Q1.

Call-back phase

9. Follow-up call to be within 10 days of the dispatch of the postal questionnaire.

10. Encourage part-completion of the questionnaire.

11. Not more than three follow-up calls to each firm.

12. Offer an e-copy according to their preference.

13. Return date for the e-copy has to be within five days.

14. Update the E-QUESTIONNAIRE.

APPENDIX 2 QUESTIONNAIRE

Section A Performance

1. How large has your firm been in the last five years?

	1999	2000	2001	2002	2003(Estimate)
Turnover (£)	_____-____	_____-____	_Founded_	__£150k__	__£750k__
Employment	_____-____	_____-____	_Founded_	____4____	____6____
Exports (£)	_____-____	_____-____	_Founded_	__£150k__	__£750k__

2. (a) How many new or significantly improved products (goods or services) have you introduced in the last five years? __1__

   (b) How many do you intend to introduce in the next five years? __4__

3. What proportion of your sales (%) are due to these new products (goods or services)?

	1999	2000	2001	2002	2003(Estimate)
Sales	_____-____	____-____	_Founded_	__£150k__	_£350k___

4. (a) If you have gone to IPO (Initial Public Offering), when was that? mm/yy __N/A__

   (b) If you intend to go to IPO, when might that be? mm/yy _05/06__

5. How much patenting activity have you undertaken?

	1999	2000	2001	2002	2003(Estimate)
Grant of patent	______-____	_____-____	_Founded_	___0____	____0____
Filing of patent	______-____	_____-____	_Founded_	___0____	____2____

Section B Resources

1. How many full-time staff do you have?

Manual	__0___
Clerical	__0___
Technical/Scientific	__3___
Managerial	__1___

2. What percentage of these staff types have a university degree or the equivalent?

Technical/Scientific staff	___100 (%)__
Managerial staff	__100 (%)__

3. What are your training costs as a percentage of your total labour costs? ____10____ (%)

4. What is your current annual R&D expenditures? __ £300____000s

5. Do you have a R&D department? Yes

6. On average, how long do you take from getting a new idea to launching of a new product or process? __15__ (months)

Section C Collaboration And Co-operation

1. Firms use collaborators to develop new or improved products, processes or organisational structures. Where are your collaborators located? (Please tick)

Collaborators \ Locations:	Local	Scotland	UK	Europe	World
Suppliers	__√__	__√__	__√__	__√__	__√__
Customers	______	______	______	__√__	__√__
Competitors	______	______	______	______	__√__
Research bodies	______	__√__	__√__	______	__√__
Government bodies	__√__	__√__	__√__	__√__	______
Professional / Trade	__√__	__√__	__√__	______	__√__
Financing	__√__	__√__	______	______	__√__

2. How frequently do you have contact with them?
(Mark on a scale of 1 to 5, where 1 = infrequent and 5 = frequent; mark 0 if no contact at all)

Suppliers	__5__
Customers	__5__
Competitors	__3__
Research bodies	__3__
Government bodies	__4__
Professional / Trade	__2__
Financing	__2__

3. How many collaborative arrangements do you have for each purpose they serve?
Enter the number (e.g. 1, 3, 10 etc.).

Collaborators \ Purposes:	Capital	Information	IP	Production	Recruit	R&D	Marketing
Suppliers	__1_	_4__	__1_	12 approx	_____	_2__	_____
Customers	_____	_4__	_____	_____	_____	_2__	_4__
Competitors	_____	_1__	__1_	_____	_____	_____	_____
Research bodies	_____	_____	_____	_____	_____	__3_	_____
Government bodies	__2_	_1__	_____	_____	_____	_____	_2__
Professional / Trade	_____	_1__	__1_	_____	_____	_____	_1__
Financing	__1_	_1__	_____	_____	_____	_____	_____

Section D Embeddeddness

1. Do you actively recruit technical and scientific staff within Scotland? Yes

2. Does staff mobility encourage you to form links with other firms? Yes

3. What was the activity of your firm's founder before start-up? (Tick one below)

	Self-employed	Unemployed	University	Govt. research lab	Another firm
Scotland	____	____	____	____	____
UK	____	____	____	____	__√_
Abroad	____	____	____	____	____

4. What percentages (%) of your current sales and purchases are in each of these markets?

	Local	Scotland	UK	Europe	World
Sales (%)	______	______	______	__10__	__90__
Purchases (%)	__25__	__25__	__25__	______	__25__

Section E Innovation

1. How much do you currently spend per year directly on innovation? (e.g. R&D + purchase of capital equipment + patents + licences + training)

   Innovation expenditure £ ___400___000s

2. How important are these sources of information in stimulating innovation in your firm? (Mark on scale of 1 to 5, where 1 = unimportant, 5 = very important and mark 0 if irrelevant)

Internal	(e.g. R&D staff, marketing staff)	__5__
Market	(e.g. customer, supplier, competitor)	__5__
Educational & Public	(e.g. govt. agencies, universities)	__3__

3. How important are these objectives in stimulating innovation in your firm? (Again mark on the same 5-point scale)

Increased productivity	__3__
Improved products (extended product range)	__5__
Increased or retained market share	__5__
Better compliance (e.g. to regulations)	__3__

4. How important are these factors in hampering innovation in your firm? (Again mark on the same 5-point scale)

Economic	(e.g. cost, finance, pay-off uncertainty)	__5__
Firm specific	(e.g. lack of skilled personnel)	__5__
Other	(e.g. regulations, taxation, imitation by others)	__2__

END OF QUESTIONNAIRE : PLEASE RETURN IN SAE PROVIDED

APPENDIX 3 GLOSSARY OF DEFINITION OF VARIABLES

	VARIABLE	DESCRIPTION	TYPE
1	TURN9	Turnover (£'000s) in '99, e.g. TURN9 = 100	Real
2	TURN0	Turnover (£'000s) in '00, e.g. TURN0 = 100	Real
3	TURN1	Turnover (£'000s) in '01, e.g. TURN1 = 100	Real
4	TURN2	Turnover (£'000s) in '02, e.g. TURN2 = 100	Real
5	TURN3	Turnover (£'000s) in '03, e.g. TURN3 = 100	Real
6	EMP9	Employment (number) in '99, e.g. EMP9 = 3	Count
7	EMP0	Employment (number) in '00, e.g. EMP0 = 3	Count
8	EMP1	Employment (number) in '01, e.g. EMP1 = 3	Count
9	EMP2	Employment (number) in '02, e.g. EMP2 = 3	Count
10	EMP3	Employment (number) in '03, e.g. EMP3 = 3	Count
11	INVST9	Investment (£'000s) in '99, e.g. INVST9 = 88	Real
12	INVST0	Investment (£'000s) in '00, e.g. INVST0 = 88	Real
13	INVST1	Investment (£'000s) in '01, e.g. INVST1 = 88	Real
14	INVST2	Investment (£'000s) in '02, e.g. INVST2 = 88	Real
15	INVST3	Investment (£'000s) in '03, e.g. INVST3 = 88	Real
16	NEWPRD	Number of new products in the last five years, (non-negative integer)	Count
17	PRD5	Number of new products in the next five years, (non-negative integer)	Count
18	SALE9	Proportion of sales (%) due to new products, e.g. SALE9 = 20	Real
19	SALE0	Proportion of sales (%) due to new products, e.g. SALE9 = 20	Real
20	SALE1	Proportion of sales (%) due to new products, e.g. SALE9 = 20	Real
21	SALE2	Proportion of sales (%) due to new products, e.g. SALE9 = 20	Real
22	SALE3	Proportion of sales (%) due to new products, e.g. SALE9 = 20	Real
23	IPO1	Date of IPO, integer variable with four variables e.g. IPO1 = 1199 means IPO in Nov' 1999	Integer
24	IPO2	Date intended to go to IPO, integer variable with four variables e.g. IPO2 = 0104 means IPO intended in Jan' 2004	Integer
25	PATG9	Grant of patent (number) in '99, e.g. PATG9 = 6	Count
26	PATG0	Grant of patent (number) in '00, e.g. PATG0 = 6	Count
27	PATG1	Grant of patent (number) in '01, e.g. PATG1 = 6	Count
28	PATG2	Grant of patent (number) in '02, e.g. PATG2 = 6	Count
29	PATG3	Grant of patent (number) in '03, e.g. PATG3 = 6	Count
30	PATF9	Filing of patent (number) in '99, e.g. PATF9 = 6	Count
31	PATF0	Filing of patent (number) in '00, e.g. PATF0 = 6	Count
32	PATF1	Filing of patent (number) in '01, e.g. PATF1 = 6	Count
33	PATF2	Filing of patent (number) in '02, e.g. PATF2 = 6	Count
34	PATF3	Filing of patent (number) in '03, e.g. PATF3 = 6	Count
35	MANU	Full-time manual workers (numbers), e.g. MANU = 7	Count

36	CLER	Full-time clerical workers (numbers), e.g. CLER = 7	Count
37	TECH	Full-time technical workers (numbers), e.g. TECH = 7	Count
38	MANG	Full-time managerial workers (numbers), e.g. MANG = 7	Count
39	TECHP	Proportion of technical workers (%) with higher education,	Real
40	MANGP	Proportion of managerial workers (%) with higher education,	Real
41	TCOST	Training costs as a %age of total labour costs, e.g. TCOST = 13	Real
42	RDEXP	Annual R & D expenditures (£'000's), e.g. RDEXP = 18	Real
43	RDDEP	Presence of R & D department (0, 1), (Y = 1, N = 0),	Binary
44	PRDLED	Time (months) taken from idea generation to launch of new product	Real
45	SUPL	The location of the supplier, (0, 1) e.g. SUPL = 1 means local	Binary
46	SUPSC	Location of the supplier, e.g. SUPSC = 1, means in Scotland	Binary
47	SUPUK	Location of the supplier, e.g. SUPUK = 1, means in UK	Binary
48	SUPEU	Location of the supplier, e.g. SUPEU = 1, means in Europe	Binary
49	SUPW	Location of the supplier, e.g. SUPW = 1, means outside Europe	Binary
50	CUSL	Location of the customer, e.g. CUSL = 1, means local	Binary
51	CUSSC	Location of the customer, e.g. CUSSC = 1, means in Scotland	Binary
52	CUSUK	Location of the customer, e.g. CUSUK = 1, means in UK	Binary
53	CUSEU	Location of the customer, e.g. CUSEU = 1, means in Europe	Binary
54	CUSW	Location of the customer, e.g. CUSW = 1, means outside Europe	Binary
55	COML	Location of the competitor, e.g. COML = 1, means local Location of	Binary
56	COMSC	the competitor, e.g. COMSC = 1, means in Scotland	Binary
57	COMUK	Location of the competitor, e.g. COMUK = 1, means in UK	Binary
58	COMEU	Location of the competitor, e.g. COMEU = 1, means in Europe	Binary
59	COMW	Location of the competitor, e.g. COMW = 1, means outside Europe	Binary
60	RESL	Location of the research bodies, e.g. RESL = 1, means local	Binary
61	RESSC	Location of the research bodies, e.g. RESSC = 1, in Scotland	Binary
	RESUK	Location of the research bodies, e.g. RESUK = 1, means in UK	Binary
62	RESEU	Location of the research bodies, e.g. RESEU = 1, in Europe	Binary
63	RESW	Location of the research bodies, e.g. RESW = 1, outside Europe	Binary
64	GOVL	Location of the government bodies, e.g. GOVL = 1, means local	Binary
65	GOVSC	Location of the gov. bodies, e.g. GOVSC = 1, in Scotland	Binary
66	GOVUK	Location of the government bodies, e.g. GOVUK = 1, in UK	Binary
67	GOVEU	Location of the government bodies, e.g. GOVEU = 1, in Europe	Binary
68	GOVW	Location of the government bodies, e.g. GOVW = 1, outside Europe	Binary
69	TRDL	Location of the professional/trade organisation, e.g. TRDL = 1, local	Binary
70	TRDSC	Location of the professional and trade organisation, e.g. TRDSC = 1 means in Scotland	Binary
71	TRDUK	Location of the professional and trade organisation, e.g. TRDUK= 1 means in UK	Binary
72	TRDEU	Location of the professional and trade organisation, e.g. TRDEU = 1	Binary

		means in Europe	
73	TRDW	Location of the professional and trade organisation, e.g. TRDW = 1 means outside Europe	Binary
74	FINL	Location of the financing organisation, e.g. FINL = 1 means local	Binary
75	FINSC	Location of the financing organisation, e.g. FINSC = 1 in Scotland	Binary
76	FINUK	Location of the financing organisation, e.g. FINUK = 1 means in UK	Binary
77	FINEU	Location of the financing organisation, e.g. FINEU = 1 in Europe	Binary
78	FINW	Location of the financing organisation, e.g. FINW = 1 outside Europe	Binary
79	SUPCON	Frequency of contact with suppliers (0,1,2,3,4,5), e.g. SUPCON = 4 means quite frequent, SUPCON = 0 means no contact	Categorical
80	CUSCON	Frequency of contact with customers (0,1,2,3,4,5), e.g. CUSCON = 4 means quite frequent, CUSCON = 0 means no contact	Categorical
81	COMCON	Frequency of contact with competitors (0,1,2,3,4,5), e.g. COMCON = 4 means quite frequent, COMCON = 0 means no contact	Categorical
82	RESCON	Frequency of contact with research bodies (0,1,2,3,4,5), e.g. RESCON = 4 means quite frequent, GOVCON = 0 means no contact	Categorical
83	GOVCON	Frequency of contact with government bodies (0,1,2,3,4,5), e.g. GOVCON = 4 means quite frequent , TRDCON = 0, no contact	Categorical
84	TRDCON	Frequency of contact with professional & trade bodies (0,1,2,3,4,5), e.g. TRDCON = 4 means quite frequent, FINCON = 0, no contact	Categorical
85	FINCON	Frequency of contact with financing bodies (0,1,2,3,4,5), e.g. FINCON = 4 means quite frequent, FINCON = 0 means no contact	Categorical
86	SUPALL	Number of alliances with supplier e.g. SUPALL = 5	Count
87	CUSALL	Number of alliances customer, e.g. CUSALL = 5	Count
88	COMALL	Number of alliances with competitor, e.g. COMALL = 5	Count
89	RESALL	Number of alliances with research bodies, e.g. RESALL = 5	Count
90	GOVALL	Number of alliances with government bodies, e.g. GOVALL= 5	Count
91	TRDCAP	Number of alliances with professional & trade, TRDALL = 5	Count
92	FINCAP	Number of alliances with financing bodies, e.g. FINALL = 5	Count
93	RECRT	Recruit or do not recruit from Scotland, e. g. RECRT = 1	Binary
94	STFMO	Staff mobility encourage to form links or not, e.g. STFMO = 1	Binary
95	SELFSC	Activity of founder before start-up, 1 = self employed in Scotland	Binary
96	UNEMSC	Activity of founder before start-up, 1 = unemployed in Scotland	Binary
97	UNISC	Activity of founder before start-up, e.g. UNISC = 1 means employed at the university in Scotland	Binary
98	GRLSC	Activity of founder before start-up, e.g. GRLSC = 1 means employed at govt. research lab in Scotland	Binary
99	OTHSC	Activity of founder before start-up, e.g. OTHSC = 1 means employed at others in Scotland	Binary
100	SELFUK	Activity of founder before start-up, 1 = self employed in UK	Binary

101	UNEMUK	Activity of founder before start-up, 1 = unemployed in UK	Binary
102	UNIUK	Activity of founder before start-up, 1 = employed at a UK university	Binary
103	GRLUK	Activity of founder before start-up, e.g. GRLUK= 1 means employed at govt. research lab in UK	Binary
104	OTHUK	Activity of founder before start-up, 1 = employed at others in UK	Binary
105	SELFAB	Activity of founder before start-up, 1 = self employed outside UK	Binary
106	UNEMAB	Activity of founder before start-up, 1 = unemployed outside UK	Binary
107	UNIAB	Activity of founder before start-up, e.g. UNIAB = 1 means employed at the university outside UK	Binary
108	GRLAB	Activity of founder before start-up, e.g. GRLAB = 1 means employed at the govt. research lab outside UK	Binary
109	OTHAB	Activity of founder before start-up, e.g. OTHAB = 1 means employed at others outside UK	Binary
110	SALL	Proportion of sales from local (%), e.g. SALL = 23	Real
111	SALSC	Proportion of sales from Scotland (%), e.g. SALSC = 23	Real
112	SALUK	Proportion of sales from UK (%), e.g. SALUK = 23	Real
113	SALEU	Proportion of sales from Europe (%), e.g. SALEU = 23	Real
114	SALW	Proportion of sales from outside Europe (%), e.g. SALW =23	Real
115	PURL	Proportion of purchases from local (%), e.g. PURL = 23	Real
116	PURSC	Proportion of purchases from Scotland (%), e.g. PURSC = 23	Real
117	PURUK	Proportion of purchases from UK (%), e.g. PURUK = 23	Real
118	PUREU	Proportion of purchases from Europe (%), e.g. PUREU = 23	Real
119	PURW	Proportion of purchases from outside Europe (%), e.g. PURW = 23	Real
120	INNEXP	Innovation expenditure (£'000'S) = R&D + purchase of capital equipment + patents + licences + training, e.g. INNEXP = 12	Real
121	ININF	Importance of internal source of information for innovation	Categorical
122	MKINF	Importance of market source of information for innovation	Categorical
123	EDINF	Importance of educational source of information for innovation	Categorical
124	PRDOB	Importance of increased productivity as an objective in stimulating innovation, e.g. PRDOB = 3	Categorical
125	IMPDOB	Importance of improved products as an objective in stimulating innovation, e.g. IMPDOB = 3	Categorical
126	MKTOB	Importance of increased market share as an objective in stimulating innovation, e.g. MKTOB = 3	Categorical
127	COMOB	Importance of better compliances with regulations as an objective in	Categorical
128	ECFAC	stimulating innovation, e.g. COMOB = 3	
129	FRMFAC	Importance of economic factors in hampering innovation	Categorical
	OTHFAC	Importance of firm factors in hampering innovation	Categorical
		Importance of other factors in hampering innovation	Categorical

APPENDIX 4 LIST OF SIC CODES

Butchart's High Technology Industries –A New UK Definition

Manufacturing

2570 Pharmaceutical Products

3301 Office Machinery Manufactures

3302 Electronic data processing equipment

3441 Telecommunications Equipment

3442 Electrical Instruments & control systems

3443 Radio & electronic capital goods

3444 Components other than active components for electronic equipment

3453 Active components & electronic sub-assemblies

3710 Measuring, Checking & precision Instrument

3720 Medical & Surgical Equipment & Orthopaedic Appliances

3732 Optical precision instruments

Services

7902 Telecommunications

8394 Computing Services

9400 Research and Development

Thompson's Definition of High Technology based on US SIC

2831 Biological Products

2833 Medicinal & Botanicals

2834 Pharmaceuticals Preparations

3573 Electronic computing equipment

3579 Office Machines

3661 Telephone & telegraph apparatus

3662 Radio & TV communications equipment

3674 Semiconductor & related devices

3679 Electronic components

3829 Measuring and controlling

3841 Surgical &medical instruments

7391 Research & development labs