Innovation in Ireland’s ‘High-Technology’ Businesses: The Roles of Interaction and Proximity

by

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The author hereby declares that except where duly acknowledged,
this thesis is entirely his own work and
has not been submitted for any degree in the
National University of Ireland, or in any other University.

This thesis is dedicated to Ann Lynch,
my wife and best friend.

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Abstract

This thesis explores the drivers of innovation in Irish high-technology businesses and estimates, in particular, the relative importance of interaction with external businesses and other organisations as a source of knowledge for innovation at the business-level. The thesis also examines the extent to which interaction for innovation in these businesses occurs on a local or regional basis.

The study uses original survey data of 184 businesses in the *Chemical and Pharmaceutical*, *Information and Communications Technology* and *Engineering and Electronic Devices* sectors. The study considers both product and process innovation at the level of the business and develops new measures of innovation output. For the first time in an Irish study, the incidence and frequency of interaction is measured for each of a range of agents, other group companies, suppliers, customers, competitors, academic-based researchers and innovation-supporting agencies. The geographic proximity between the business and each of the most important of each of each category of agent is measured using average one-way driving distance, which is the first time such a measure has been used in an Irish study of innovation.

Utilising econometric estimation techniques, it is found that interaction with customers, suppliers and innovation-supporting agencies is positively associated with innovation in Irish high-technology businesses. Surprisingly, however, interaction with academic-based researchers is found to have a negative effect on innovation output at the business-level.

While interaction generally emerges as a positive influence on business innovation, there is little evidence that this occurs at a local or regional level. Furthermore, there is little support for the presence of localisation economies for high-technology sectors, though some tentative evidence of urbanisation economies. This has important implications for Irish regional, enterprise and innovation policy, which has emphasised the development of clusters of internationally competitive businesses. The thesis brings into question the suitability of a cluster-driven network based approach to business development and competitiveness in an Irish context.

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CHAPTER 1: INTRODUCTION - THESIS RATIONALE AND CONTRIBUTIONS

Ireland's emergence from the 'Celtic Tiger' era raises two critical questions for continuing economic development, from the perspectives of public policy, enterprise development, innovation and regional balance. The first is what drives innovation in Ireland's high-technology businesses, which have played a major role in the growth in Irish productivity, employment and living standards through the 'Celtic Tiger' period and have been identified by policymakers as fundamental to moving the Irish economy 'up the value chain'. The second question arises from the recognised importance of interaction as a source of knowledge for innovation and concerns the extent to which this interaction occurs at local/regional level in Ireland and the factors determining the geographical distribution of these interactions.

This thesis seeks to address these questions by using a theoretically-grounded approach to analyse primary data collected by means of a specially designed survey of innovation and its sources in Irish high-technology businesses. The questions and answers have important implications for Irish and European policy makers, who, since the adoption of the Lisbon Agenda in 2000, are increasingly focused on encouraging innovation in knowledge-based sectors to support future growth and competitiveness. It is the intention of this study to contribute to the understanding of the factors driving innovation in Irish high-technology businesses and the extent to which innovation is spatially bounded, thereby making a useful contribution to policy formulation in Ireland.

This is the first Irish study to estimate the relative importance of a range of potential interaction agents from which a business may source knowledge for innovation. These interaction agents are customers, suppliers, competitors, academic-based researchers and innovation-supporting agencies. Given the importance of foreign-owned businesses in Ireland, interaction between Irish based subsidiaries and other businesses in the same organisation (to be referred to as other group companies) is analysed. This thesis assesses the relative roles of internal research and development (R&D) activity and interaction agents in explaining the relative success of product and process innovation outputs in Irish 'high-technology' businesses.

A major contribution of this study is the collection and analysis of original survey data. Hitherto a lack of data on innovation at the business level has been identified as a key difficulty in understanding how businesses innovate. This study is based on a specially designed survey of 184 businesses in the *Chemicals and Pharmaceuticals*, *Information and Communications Technology (ICT)* and *Engineering and Electronic Devices* sectors.

The study uses newly developed innovation output and input indicators, including new measures of process innovation output, interaction frequency and the diversity of interaction for innovation. This thesis is also the first Irish study to analyse interaction with a range of potential interaction agents and the first to use time-distance as a measure of geographic proximity. This thesis also estimates the importance of various kinds of agglomeration for business-level innovation output.

The objective of this Chapter is to briefly introduce the theoretical and empirical literature on which this study builds and to set out the policy context to which the study contributes. The Chapter is structured in the following way. Section 1.1 presents the orientation and contributions of this study. It outlines relevant theoretical and empirical literature and the policy issues that make it timely and relevant. Section 1.2 outlines the methods of analysis. Finally Section 1.3 presents the structure of the thesis, outlining the contents of subsequent Chapters.

1.1 Orientation and Contributions

This thesis is motivated by two simultaneous developments. The first is a broad and growing theoretical and empirical literature on the determinants of innovation. This literature draws on work in regional competitiveness, agglomeration economies and knowledge spillovers, economic geography, entrepreneurship, corporate strategy, evolutionary economics and innovation systems. Chapters 2 and 3 survey relevant literature to place this thesis in a conceptual context and to inform the approach adopted in subsequent Chapters.

The second motivation is an increased awareness and attention from policy-makers on the need for deeper understanding of the factors that drive innovation in businesses. Ireland's policy-makers have increased their focus on productivity gains from innovation as a source of future Irish growth and competitiveness, post-'Celtic-Tiger'. This study makes a very important policy contribution. The policy implications for Ireland arising out of this study are discussed throughout the Chapters 5, 6 and 7, and are drawn together in Chapter 8.

First, the two motivating forces are considered in more detail.

1.1.1 Theoretical Context

Several hypotheses have been suggested to explain business' innovative performance, including business size and market structure, the stage of the product life cycle of the business, the extent of interaction between businesses and their suppliers and buyers, business competencies and the institutional structure within which businesses operate. The literature on which these hypotheses are based is discussed in detail in Chapter 2.

While earlier studies on innovation looked to the characteristics of the business to explain innovation performance, more recent studies have focused less on the business itself, and more on its position within a network or system of interactions and relationships. The importance of these interactions and networks is based on knowledge spillovers. These derive from the public good nature of knowledge, which is non-rival and partially excludable. One person's use of knowledge does not diminish the ability of another to use the same knowledge, though the use of patenting may prevent some from fully availing of new knowledge. This raises the prospect of spillovers of knowledge, or positive externalities from new knowledge creation. In particular the transfer of tacit, uncodified knowledge is facilitated by shared experiences and trust, which are developed through interaction. Von Hippel (1988) and Lundvall (1988) stress interaction between users of knowledge and producers of knowledge as a source of innovation.

There is support from a number of different literatures for the view that the flow of knowledge, particularly tacit knowledge, is geographically bounded (for example, Lundvall 1988; Glaesar et al 1992; Porter, 1998; Florida, 2002). Businesses are more likely to interact with other businesses, academics and innovation-supporting agencies that are closer to them geographically. As Glaesar et al expressed it, "intellectual breakthroughs must cross hallways and streets more easily than oceans and continents" (1992:1127). Knowledge spillovers have been central to what Moulaert and Sekia (2003) describe as 'territorial innovation models'. These include innovative mileux, industrial districts, clusters, regional innovation systems and learning regions. The potential for knowledge spillovers has been suggested as an explanation for differences in regional growth rates and the agglomeration of economic activity. In addition, there is empirical evidence that geographical location does matter for innovation performance.

The presence of knowledge spillovers has been identified since Marshall (1890) as a factor in the agglomeration of economic activity. However, there has been a recent debate on the importance of localised knowledge spillovers in explaining agglomeration, with suggestions that their role has been overstated. Caniels and

Romijn (2005) suggest a resolution to the debate on the importance of knowledge spillovers as a source of agglomeration is to understand better the sources of innovation in businesses, since this is where innovation occurs. By asking businesses about the relative importance of interaction for their innovation and their proximity to those with whom they interact, the mechanics of agglomeration can be better understood. This thesis endeavours to contribute to this understanding.

This study also contributes to increasing knowledge on business innovation activities by collecting and presenting new survey data on innovation, interaction and geographical proximity to interaction agents in Irish 'high-technology' businesses. Sena identifies a lack of appropriate data as the major problem underlying research on knowledge spillovers and called for an "innovation database based on survey information which could provide on spillovers" (2004:328). This study goes some way to reducing the lack of business-specific data.

There have been a small number of studies that are relevant to the area of networking for innovation by Irish businesses. Most however focus particularly on the role of knowledge spillovers from multinational businesses to local businesses (Ruane and Ugur, 2002; Hewitt-Dundas et al, 2002).

Roper (2001) estimated the relative importance of external interaction as a driver of product and process innovation in Irish businesses. This thesis considers the range of potential interaction agents, including other group companies, suppliers, customers, competitors, academic-based researchers and innovation-supporting agencies and the extent to which interaction with each is a source of knowledge for innovation. Based on the urban-hierarchy model Roper (2001) estimates whether a business' location affects innovation performance. This thesis takes a different approach by exploring the extent to which geographical proximity, measured by time-distance, affects interaction for innovation. In addition, the effects of agglomeration, both localisation and urbanisation, on innovation are analysed.

1.1.2 European and Irish Policy Context

The theoretical work on innovation and technological change and the effect on growth and development has coincided with growing attention among policy makers on ways to encourage improved business productivity through innovation. This stems from the increasing levels of international trade and globalisation.

At European Union level innovation has become a critical policy issue. The Lisbon European Council in 2000 stressed the importance of establishing policies that support research and innovation in the EU to make Europe "the world's most competitive and dynamic knowledge-based economy" (2002:8). The European Innovation Directorate states that innovation policy must place innovation "at the heart of those policy areas shaping innovation performance...for example, Research, Education, Competition and Regional Policy" (2003:3).

Irish policy-makers have also recently highlighted a crucial role for innovation as a source of future growth and competitiveness. Forfás contend that productivity growth, based on innovation and technology, must increasingly become the driver of Irish economic growth (2003:27). In its *Medium Term Review 2003-2010*, the ESRI contend that Irish industrial policy must "evolve into a process of promoting skills and processes, such as research and development" (Bergin et al, 2003:87). This emphasis on innovation has continued with the Enterprise Strategy Group (ESG), which identifies expertise in technology and product and process development as being among the critical sources of competitive advantage for the Irish economy in the future (2004:xiv).

There is a consensus from a policy perspective on how this innovation is to be encouraged. Forfás (2000) highlights the importance of technology linkages and innovation systems for stimulating innovation in Irish businesses. Among the measures recommended by Forfás are the establishment of a 'technology intelligence' network and the development of strategic collaborative partnerships between industry and third-level/state institutions (2000:82). More recently, Forfás (2003) contend that innovation depends on effective knowledge linkages between businesses, their suppliers and customers, as well as universities, research institutes, Government and their agencies. The same report proposes a science based industrial policy that aims to "foster clusters of world-class technology based companies" (2003:9). This policy, and its emphasis on clusters, implies that systems of innovation can be influenced by policy makers and that geographical proximity is important in fostering linkages.

The National Competitiveness Council also recognises the roles of interaction and proximity, or local links, in fostering interaction. It states that there is “strong evidence internationally that a business’s competitive advantage – particularly in innovation-driven industries – often lie outside the business itself and are rooted in geographic location and local industry dynamics” (2003:17).

The Enterprise Strategy Group (2004) identified key sectors with potential for future growth. These include knowledge-based, ‘high-technology’ sectors, in which Ireland, through innovation, can develop internationally competitive businesses. This focus on ‘high-technology’ businesses in policy statements makes this thesis particularly timely and relevant. More recently, in the *Strategy for Science, Technology and Innovation 2006-13*, the Irish government has committed €1.9 billion to fund research activity in third–level institutes and supports for research in private and public research centres (Department of Enterprise, Trade and Employment, 2006:13).

This thesis is focused on businesses in ‘high-technology’ sectors because of their sizeable contribution to the growth in Irish productivity, employment and economic activity through the ‘Celtic Tiger’ period from the mid-1990s to early 2000’s. The definition of high-technology sectors is presented in detail in Section 4.2 and is based on the identification of medium-high and high-technology sectors by the OECD as used for the EU Innovation Scoreboard (European Commission, 2003b).

The need to focus enterprise polices on increasing productivity and innovation expressed by policy makers is consistent with the policy prescriptions in Gallagher, Doyle and O'Leary, who contend that sustaining the Irish growth performance requires, among other things, greater emphasis on research and development, on supporting innovation in activities that generate greater value added and on the emergence of strong clusters of related and supporting internationally competitive industries (2002:15).

To meet the new policy challenges, it is important to understand the sources of innovation at the level of the business. This enables the targeting of policy measures at those areas which contribute most to successful innovation by businesses. This thesis contributes to this area by identifying the important drivers of business-level innovation in Ireland.

1.1.3 The Research Agenda

The concurrent theoretical work and the policy concerns generate a clear research agenda, to which this thesis contributes. That agenda requires evidence on the role of interaction between businesses, academic researchers and innovation-supporting agencies in generating and diffusing knowledge and increasing the level of innovation. This thesis contributes to the research agenda by presenting evidence on the relative importance of knowledge spillovers in an Irish context, specifically in relation to Irish 'high-technology' sectors.

1.2 Methods of Analysis

This thesis is based on new survey data of innovative activity of businesses in Irish 'high-technology' sectors between 2001 and 2003. A particular strength of the survey in this study is the degree of detail on interaction and proximity to interaction agents. Specifically the survey measures both the incidence and the frequency with which businesses interacted with each of six interaction agents over the three-year period. This means that the survey can identify not only if interaction occurred but to what extent it occurred.

The survey addresses both product and process innovation. It introduces an original measure of process innovation, by measuring the frequency with which new processes were introduced to the business between 2001 and 2003. This new measure is based on input from business referees who suggest it is the most appropriate way of looking at how new processes are introduced.

Most empirical studies use co-location of businesses and interaction agents in a particular region, for example the same state or region, to represent proximity. However, in this measure businesses that are located close to each other but are in neighbouring regions are not considered to be proximate while businesses co-located within a large region are considered to be proximate even though they may be distant. This is the first Irish study to use an alternative measure, average one-way driving time, which is a superior measure as it overcomes the problems associated with the use of political or administrative boundaries.

The survey also collects data on business characteristics including employment, age, growth in sales, profitability, nationality of ownership, educational qualifications of the workforce, product range characteristics of the business and perceptions of the competitive environment in which the business operates. It is important to control for these variables in order to identify the relative importance of interaction and R&D for innovation performance.

An innovation production function approach is used to model the relationship between product and process innovation outputs and the inputs to innovation. These inputs are R&D effort, the incidence or frequency of interaction with other businesses and the incidence or frequency of interaction with academic researchers and innovation-supporting agencies. The model is estimated after controlling for business characteristics.

1.3 Chapter Summary

The thesis is set out as follows. Chapter 2 presents the conceptual framework of the study. Placing innovation in the context of entrepreneurial discovery and the growth of knowledge, models of learning and innovation are presented. Innovation is defined and the innovation process is explained. It is argued that learning, which is the basis of knowledge, and innovation are social in nature. Thus, interaction is a key element of the process of innovation. The importance of geographic proximity and agglomerations of economic activity for knowledge spillovers between businesses and other institutions is considered in this Chapter. Geographic proximity may enable more frequent face-to-face interaction and greater levels of trust between interaction agents. This would facilitate the exchange and transmission of greater amounts of tacit knowledge. This forms the basis of regional innovation models and arguments for cluster-based approaches to promoting innovation in business. The Chapter concludes by formulating hypotheses to be tested empirically in subsequent Chapters for businesses in Ireland's high-technology sectors.

Chapter 3 surveys empirical work on innovation, including the small number of Irish studies. The purpose of the Chapter is to inform the choice of method of analysis adopted in subsequent Chapters. The Chapter explains the difficulties associated with measuring innovation and presents various indicators that have been utilized to date. Previous studies have analysed the roles played by R&D and interaction in promoting innovation. Stylised facts derived from empirical work on the relationships between these factors and innovative activity are identified and approaches to estimating the effect on interaction and innovation of geographical proximity are outlined. This Chapter ends by setting out the methods used to estimate the relative importance of the drivers of innovation in businesses in Ireland's high-technology sectors.

The fieldwork undertaken to produce a database of innovative activity in Ireland's 'high-technology' sectors is presented in Chapter 4. This Chapter justifies the selection of the sectors for analysis and details how the sample frame is constructed. The survey instrument and the method of administering the survey are discussed in detail. The degree to which the sample frame is representative of the population of Irish 'high-technology' businesses is considered and the Chapter closes with an analysis of item and survey non-response.

Chapter 5, the first Chapter to present the results of the survey, contains a descriptive statistical analysis of the results. This Chapter presents the innovation activities of businesses in Irish high-technology sectors, including the level of product and process innovation output, R&D activity and the incidence and frequency of interaction for product and process innovation across the range of potential interaction agents. The spatial patterns of interaction among high-technology businesses and between these businesses and other institutions are set out. The results are analysed by sector, indigenous and foreign ownership, business age and business size to shed light on differences in innovation activity across each category. This contributes to theoretical and empirical literature on the importance of these factors for innovation activity and highlights issues of concern to policy makers focused on businesses within each category.

Innovation production functions are estimated in Chapter 6. While controlling for relevant business characteristics that may be expected to affect innovation output, product and process innovation are modelled as functions of R&D effort within the business and interaction with other businesses and institutions. Appropriate estimation techniques are used to estimate the relative importance of R&D and interaction for innovation with a range of interaction agents for innovation output. Five estimations are reported, using alternative innovation output indicators as dependent variables. These include three product innovation models and two process innovation models. At the end of Chapter 6 the results of these estimations are summarised and their implications for Irish innovation and enterprise policies are presented in detail. In particular the results raise questions on the efficacy of polices directed at increasing networking and collaboration between business and third-level researchers.

Chapter 7 analyses the effect of geographical proximity on innovation performance. This tests whether knowledge spillovers are geographically bounded. First, the effect of geographical distance on the likelihood of interaction with each interaction agent is estimated. Second, the role of agglomeration effects on business-level innovation output is estimated. These results are considered in the context of Irish regional development policy. In particular the results have implications for the appropriateness of cluster-based regional policies, as outlined in the National Spatial Strategy (Department of Environment and Local Government, 2002). These policy issues are discussed in detail at the end of Chapter 7.

Chapter 8 presents conclusions from the research, draws together the policy implications from earlier Chapters and suggests a future research agenda.

CHAPTER 2: THE DRIVERS OF INNOVATION: R&D, INTERACTION AND GEOGRAPHIC PROXIMITY

As noted in Chapter 1, this study is partly motivated by the broadly-based and growing literature on the drivers of business-level innovation. Contributions to explaining how innovation occurs have emerged from several strands of literature including management, evolutionary economics and theories and frameworks relating to agglomeration economies, including learning regions, innovative mileux, industrial districts, clusters and regional innovation systems.

This Chapter surveys these literatures to identify the factors that determine the incidence and level of innovation in a business. These factors are subsequently tested for Irish high-technology businesses using new survey data, and the results reported in Chapters 5 to 7. This Chapter is organised into six sections that are set out as follows.

The first section considers the importance of knowledge and innovation as a driver of economic growth and the role of knowledge creation in the market process. The objective of this section is to explain why the study of innovation is important for economists. It is argued that, from an economic perspective, innovation is important to the extent that it contributes to and sustains growth and improvements in standards of living. Furthermore, knowledge creation and innovation provides a basis with which to understand a market system. This section continues by defining knowledge in the context of an economy and describing the characteristics of knowledge that facilitate its creation and growth through interaction between businesses and other organisations within an economic system.

Having considered how knowledge, which is the basis of innovation, is created, the focus of Section 2.2 is on innovation itself. This section explores the meaning of innovation in business. The objective is to develop a definition of innovation, based on current innovation literature, that may be used to explore the drivers of innovation in Irish 'high-technology' businesses. This section also presents models of the process of innovation within business, which demonstrate that market demand is the critical aspect in the conception and introduction of new products and processes. It is seen in this section that an important element of recent innovation models is interaction with other businesses and institutions.

Section 2.3 considers in more depth the theoretical bases for interaction as a source of knowledge for innovation. It is argued that interaction is important for new knowledge creation and innovation because of the public good nature of knowledge and the existence of knowledge spillovers. The social aspect of learning and the requirement that users and producers of innovation must communicate needs and capabilities respectively emerge as the fundamental reasons why interaction influences the creation of new knowledge and, in turn, innovation.

Section 2.4 presents a model of business innovation that draws on the important role played by interaction as a source of knowledge. This model emphasises market-demand as the stimulus for business innovation, replacing the traditional linear model that suggests business innovation is driven predominantly by new technologies. If, as argued in Sections 2.3 and 2.4, interaction is an important source of knowledge for business innovation, this prompts the question of what influences the extent of interaction between businesses and other organisations.

This is the focus of Section 2.5, which considers the spatial aspects of knowledge spillovers. There is a growing literature, surveyed in this section, that suggests that knowledge spillovers are spatially bounded or, at least, made more possible by geographical proximity. If knowledge spills over through interaction between individuals, geographic proximity may facilitate more frequent interaction and, in turn, greater opportunity for knowledge spillovers. The importance of agglomeration economies, which suggest that businesses benefit from being located within a concentration of other businesses, and geographical proximity for innovative activity are discussed.

The theoretical literature reviewed in this Chapter prompts a series of hypotheses on the factors that drive business-level innovation and these are set out in the final section of this Chapter. These hypotheses will be tested in subsequent Chapters for Irish ‘high-technology’ sectors using new survey data.

2.1 Innovation and the Economy

This section argues that innovation is a critical concept in understanding and explaining economic growth and in comprehending the market process itself. This means that innovation and its drivers at the level of individual businesses is an important area of research for economists. First in this section exogenous and endogenous growth theories are briefly presented and the importance of technological change within these models is highlighted. The importance of this in the current Irish context is also discussed. Second, models are presented which explain the competitive market system as a process of continuous knowledge creation and innovation. These put forward a dynamic system in which innovation by businesses is the foundation on which market economies are built.

2.1.1. Innovation as the Driver of Economic Growth

Since Schumpeter (1942) identified the process of what he termed "creative destruction" as the essential fact about capitalism, innovation has increasingly been seen as the driver of economic growth and development. Schumpeter states that the "fundamental impulse that sets and keeps the capitalist engine in motion comes from new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organisation that capitalist enterprise creates" (1942:83). More recently Baumol (2002) identifies innovation as the engine of growth in market economies.

Models of economic growth, both neo-classical and endogenous theories, imply a critical role for technological change in driving economic growth. Sena notes that economists generally agree that total factor productivity growth is the main determinant of long-run economic growth, and that total factor productivity growth is closely linked to innovation in the economy (2004:312).

Growth Models: Exogenous and Endogenous

Neo-classical growth models, such as that presented by Solow (1956), consider technological progress to be an exogenous variable. This means that the rate of technological progress is not determined by the actions of economic agents but is like "manna from heaven" (Jones, 2002:36). These models are not specifically concerned with where technological progress comes from, but instead assume that it is growing at a constant rate. The Solow model suggests that total factor productivity, or output per unit of total input, grows at the same rate as the growth in technology. This means that sustained economic growth results from improvements in productivity based on new technology. Jones (2002) illustrates that in the Solow model without technological progress, per capita growth eventually decreases due to diminishing marginal returns to capital. This implies that the presence of technological progress more than offsets the decline in the marginal productivity of capital.

Solow (1956) presents a growth accounting framework that identifies the contribution to per capita growth of capital per worker and total factor productivity. Total factor productivity, which is often regarded as an estimate of technological progress, is estimated as a residual in the growth accounting framework.

Instead of assuming that growth occurs due to unmodelled advances in technology, the new endogenous growth model focuses on those factors that underpin technological progress. Romer (1990), building on new theories of imperfect competition, develops a growth model in which technological progress occurs as a result of the actions of profit-maximising businesses who seek to develop new and better products and processes.

Romer (1990) contends that knowledge has public good characteristics in that it is non-rivalrous and partially excludable. Non-rivalry means that one individual's use of a piece of knowledge does not diminish the ability of another individual to use the same knowledge. The non-rival nature of knowledge means that knowledge has a fixed cost of production and a zero marginal cost. Knowledge is not a pure public good as it is only partially excludable. A good is excludable if it is not possible to prevent an individual from enjoying the benefits of the good without paying for its use. The degree to which a good is excludable determines the extent to which its owner can charge for its use. Patents, copyright and secrecy are some of the approaches used to exclude others from using particular knowledge.

Both exogenous and endogenous growth models imply that technological progress and innovation are critical drivers of economic growth by improving total factor productivity. However, Baumol argues that recent models of growth have "not sought to explore the heart of the free-market growth process, which is the competitive pressure that forces businesses to create, seek out and promote innovations" (2002:15).

Since innovation is clearly a critical factor driving economic development and growth within a market economy, Baumol (2002) suggests that economists should be more concerned directly with the factors that promote innovation. This thesis seeks to contribute to that research agenda by exploring the factors that drive innovation at the business-level.

This research agenda is particularly relevant in the current Irish context post-'Celtic Tiger'. Kennedy (2001) notes that all of the acceleration in the growth of output during the 'Celtic Tiger' is accounted for by the acceleration in the growth of employment. This creates a challenge for the Irish economy which has now achieved full employment levels. The observed slowdown in the rate of labour force expansion means that productivity growth through innovation will become increasingly important for raising output and living standards. It is important that policies directed at raising productivity are educated by research into the factors that drive innovation at the business-level. This thesis is concerned directly with this important policy area.

While knowledge growth and innovation is critically important in both exogenous and endogenous growth models, it is also emerging as an important concept in understanding how market economies function. This is a further reason why economists must be directly concerned with research on business innovation and the factors that influence it. This is considered in the next section.

2.1.2. Innovation and the Market Process

There is a growing consensus that static general equilibrium models do not adequately reflect the way in which businesses and consumers relate within a competitive market economy. Harper contends that "modern Walrasian perfect competition theory does not explain market processes, which is the way in which competitive market forces bring about changes in prices and quantities and the introduction of new products and processes" (1996:8). This echoes the criticism of general equilibrium theory by Nelson (1991), who states that its focus has largely been on how well an economy allocates resources, given preferences and technologies. He characterises general equilibrium theory as one in which businesses are given known choice sets and can easily choose the actions within those sets that achieve required objectives. These businesses may be constrained, for example by the available technologies, but their objective, which is generally profit maximisation, can be identified and can be measured. The overall result is that businesses do what is determined by the conditions that they face and by unique attributes that they have, perhaps location or technology. Thus businesses behave differently because they operate within different parameters. However, if the parameters change so would business behaviour.

It is useful in the context of a study of the drivers of innovation to consider, as Nelson (1991) does, the example of research and development (R&D) activity in a general equilibrium context. The objective of profit maximisation may provide an incentive to businesses to engage in R&D when the returns from the investment are seen to outweigh the costs. The business though must be aware of, or at least capable of estimating, both the costs and benefits. While the costs of R&D activity may be reasonably estimated *ex ante*, the success of R&D in generating a commercially exploitable product or process and success in the market for this new product or process can only be judged *ex post*. Even with intellectual property protection market success is difficult to estimate. Kline and Rosenberg (1986) note that innovation is a highly uncertain process, as successful innovation involves achieving technological breakthrough and economic viability. More radical innovations are characterised by greater levels of uncertainty, in terms of the market response, the technical performance and the ability of the business to adopt and adapt to the required changes. This suggests that the process of business innovation cannot be understood in the context of the cost and benefit trade-offs of general equilibrium theory.

More generally, Dosi et al (1989) contend that a business cannot understand its world as implied in neo-classical or general equilibrium theory since the world is too complex for a business to comprehend. This means that a business cannot calculate optimal strategies. They argue that, in relation to strategy, there is a range of options where a business simply has to choose a course without knowing how it will turn out. In this context businesses choose different strategies and this leads to different core capabilities and structures. This choice leads to different paths, some profitable and some unprofitable given what other businesses are doing and how markets evolve.

Unprofitable strategies mean that businesses must change structure and develop new core capabilities, operate the ones they have more effectively or else fail. The implication of these arguments is that businesses cannot treat innovation activity as a game of choosing appropriate inputs to generate a known or even likely output.

The public-good nature of knowledge also presents a difficulty for Walrasian perfect competition in modelling innovation decisions. Due to the only partially excludable nature of new knowledge, businesses may be unable to appropriate for themselves the full benefit of an innovation. In other words, innovations may generate benefits, for businesses or industries far from the industries in which they were created, for which the innovator is not compensated. There are many examples of this, such as the impact on many industries of the development of the personal computer. The generation of new knowledge creates a private return for the innovator, but also a social return. Mansfield et al (1977) find that the social rate of return from seventeen innovations in manufacturing industries is over double the private rate of return. In this context, as with all public goods, the level of investment in innovation may be less than the socially-optimal level. The approaches to solving this market failure include government funding for or direct provision of research, for example in third-level institutions and the granting of monopoly patent rights to enable businesses to appropriate some of the benefits of innovation.

The general equilibrium model of a competitive market economy has therefore been challenged by an alternative framework that places the growth of knowledge, and by extension innovation and entrepreneurship, at the centre of the competitive process (Schumpeter, 1934 and 1942; Hayek, 1945; Mises, 1949; Kirzner, 1973 and 1997). This framework presents the market system as a process of testing hypotheses regarding products and processes, resulting in a continuous cycle of knowledge creation. The next section discusses the role of knowledge within the market system.

2.1.3. Knowledge and Entrepreneurial Discovery

Hayek (1945) places knowledge at the very centre of the market process. He states that "the economic problem of society…is a problem of the utilisation of knowledge not given to anyone in its totality" (1945:519). No individual actor in the market process has full information, or is aware of the optimal use of resources. As actors increase their mutual awareness the relative importance of those resources is more widely known. This increase in mutual awareness may occur by deliberate search or may occur as part of a discovery process.

Demmert and Klein (2003) distinguish between search activity and entrepreneurial discovery. Search activity involves agents seeking new knowledge but that knowledge fits into the existing interpretation. For example, businesses may search for suppliers and gather information on prices and quality. This is new information, and its discovery may not be costless. Agents in the market may experience unavailability of knowledge or information, which may be discovered through deliberate search. This is a case of imperfect information. Uncovering this information does not involve entrepreneurial activity. An example of this type of search is finding out the prices charged by competitors. This knowledge may be unavailable to a particular agent but can be uncovered, albeit at a cost. The salient aspect in this case is that the agent is aware of what is unknown to them. Lundvall (1988) characterises search activity as seeking an answer to a known problem. Some businesses may establish R&D departments that are constantly engaged in search activities, though this is also the situation for departments that are involved in market analysis.

Search activity is distinguished from discovery (Kirzner, 1997) and exploring (Lundvall, 1988), which arises where individuals do not know what answer they are looking for, indeed they may not be aware of the problem to be solved. Kirzner (1997:62) characterises entrepreneurial discovery as systematically and gradually pushing back the boundaries of “sheer ignorance”. Businesses and individuals in the market, through the process of discovery learn more and more about each other and the market process itself. Sheer ignorance differs from imperfect information in that the ignorant actor does not know what is unknown. Kirzner (1997) defines market equilibrium as the complete absence of sheer ignorance. Lundvall (1988) argues that discovery activity is important because, due to its weaker goal orientation relative to searching, it can result in more radical innovation. It can lead to breaks in the path dependence of previous technological advances, which may not be the situation for profit-motivated research. This is because the outcomes are not foreseen and neither are they looked for.

This construction of knowledge growth as the result of discovery is consistent with Kline and Rosenberg’s (1986) position regarding the uncertain benefits of innovation.

Research may shed new light on an existing problem, causing a shift in the interpretation of the problem, or it may lead to the discovery of new information that was knowable previously but which had gone unnoticed. The growth in knowledge through discovery is based on interaction between individuals. However, before considering how knowledge is created and grows, it is necessary to clarify what knowledge is and to address an important distinction between codified and tacit knowledge.

Codified and Tacit Knowledge

Nonaka and Takeuchi (1995) draw a clear distinction between information and knowledge. They state knowledge is information that has been placed in a particular context, suggesting that information is a necessary component of knowledge. Hayek (1945) states that knowledge is context-specific since its value depends on the time and space in which it is used. Leonard and Sensiper define knowledge as "information that is relevant, actionable, and based at least partially on experience" (1998:113).

Knowledge may be codified and/or tacit in nature (Polanyi, 1966; Nonaka and Takeuchi, 1995; Spender, 1996 and Nonaka et al, 2001). Polanyi contends that there are elements to knowledge that are not communicable when stating that "we know more than we can say" (1966:4). Leonard and Sensiper (1998) contend that knowledge exists on a spectrum, with completely explicit knowledge at one extreme and completely tacit knowledge at the other extreme. Most knowledge, they state, exists between these extremes, implying that most knowledge contains both explicit and tacit elements.

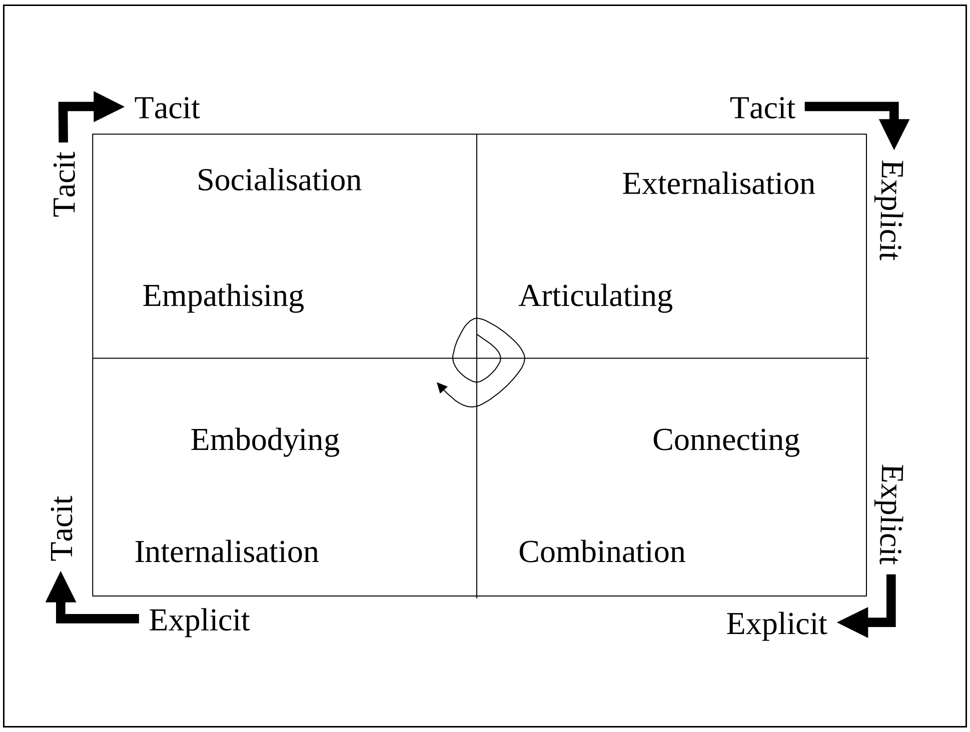
Spender (1996) argues that tacit knowledge is not necessarily impossible to codify, but rather that tacit knowledge should be considered to be knowledge that has not yet been codified. Spender (1996) provides three reasons why tacit knowledge may not be explicated. First, much knowledge is personal, restricted or biased. This means that the context within which problems are presented affect the ability of individuals to solve them. Spender states that explicit knowledge may be tacit when it is restricted to the context in which it is used. Second, tacit knowledge may involve an automatic or sub-conscious element. That is the user is unaware that tacit knowledge is being applied. Spender (1996) cites several examples of the automatic aspect of tacit knowledge, including the frequent inability of expert typists to arrange correctly the pattern of the QWERTY keyboard and the ability of expert drivers to maintain several fields of attention, from the sound of the engine to the radio to the rear-view mirror. Third, tacit knowledge contains a collective component. This is based on a distinction between knowledge that is developed by an individual and shared with others and knowledge that is part of a social system. This is consistent with Nelson and Winter's (1982) organisational routines where the collective knowledge is not fully understood by any one individual.

The distinction between codified and tacit knowledge is an important one in the context of knowledge spillovers and the role of interaction for innovation. Also, if knowledge is highly tacit geographical proximity may be important to facilitate the sharing or transmitting of that knowledge between individuals. The next section considers models of knowledge creation and growth.

2.1.4. Models of Knowledge Creation

Nonaka et al (2001) present a model of the process of knowledge creation, which comprises the four stages of socialisation, externalisation, combination and internalisation, referred to as the SECI process. Each stage comprises an interaction between codified and tacit knowledge and is shown in matrix form in Figure 2.1.

Figure 2.1 The SECI Process of Knowledge Creation



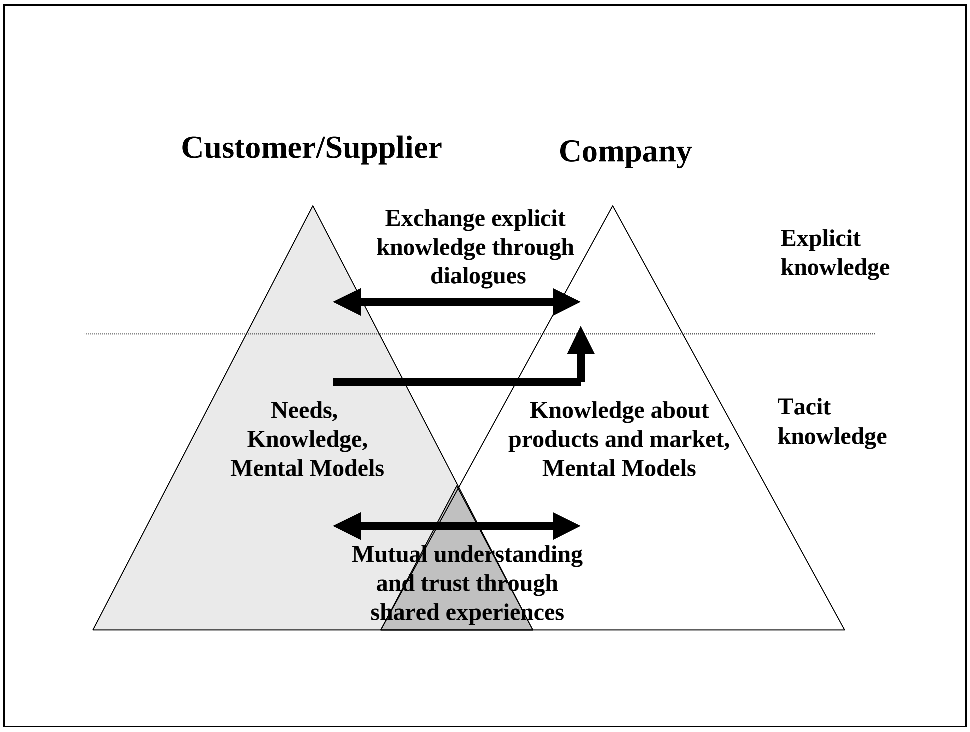
Source: Nonaka et al (2001:20)

Reading from the top left quadrant in Figure 2.1, socialisation is the process of converting new tacit knowledge through individuals' shared experiences. Tacit knowledge is difficult to codify and is context-specific, so tacit knowledge can be acquired only through individuals spending time together or living in the same environment. Individuals' experiences are shared through the act of empathizing. Externalisation is the process of making tacit knowledge codified or explicit. The tacit knowledge is articulated and written down so that it can be shared with others. It then becomes the basis for new knowledge. Combination involves the converting explicit knowledge into new, more complicated and systematic sets of explicit knowledge. Explicit knowledge is collected and combined to form new knowledge. This explicit knowledge can be converted to tacit knowledge by the embodying of that knowledge, through the process of internalisation.

Nonaka and Takeuchi (1995) and Nonaka et al (2001) stress that knowledge creation is a dynamic and continuous process. So at the centre of the SECI process is a spiral representing the movement through the four modes of knowledge creation. Knowledge created in the SECI process can lead to new spirals of knowledge creation. The process is presented to explain how organisations create knowledge and Nonaka and Takeuchi (1995) present it as a framework for knowledge creation within an organisation.

Nonaka et al (2001) contend that knowledge can be transferred beyond organisational boundaries. Knowledge created by an organisation can "trigger the mobilisation of knowledge held by outside constituents, such as customers, affiliated companies, universities or distributors" (2001:20). Figure 2.2 presents how businesses interact with other, external organisations in knowledge creation.

Figure 2.2 Interaction with External Organisations for Knowledge Creation



Source: Nonaka et al (2001:21)

Individuals within organisations exchange explicit or codified knowledge, for example in relation to product specifications or prices. Tacit knowledge can be exchanged and made explicit. For example, a business may learn more about the needs of its customers and reflect these in new product specifications or by providing information regarding their capabilities in promotional material. This sharing of tacit and explicit knowledge requires interaction between individuals inside and outside the business. There is also the sharing of tacit knowledge between individuals in each business which does not become codified or explicit. This is represented by the overlapping shaded area in Figure 2.2. This exchange of tacit knowledge can occur only where trust and shared experiences exist, which in turn requires interaction, perhaps over long periods, between individuals within the business. This implies that knowledge spillovers, particularly in relation to tacit knowledge, occur as part of a social or interactive process. Of course many market transactions do not involve the spillover or sharing of tacit knowledge between the participants. These may be anonymous and/or small, one-off market transactions in which case the company and customer/supplier triangles depicted in Figure 2.2 would not overlap.

The idea that knowledge creation occurs in a process of interaction among businesses and between businesses and other organisations, which is illustrated by Nonaka et al (2001), will be discussed later in this Chapter in Section 2.3, when the role of interaction as a driver of innovation in business is considered. However, before the factors that influence business innovation are considered it is necessary to identify what innovation means. The next section considers definitions of innovation that have emerged in the literature and sets out the definition of innovation used in this study. The section also describes how innovation occurs within individual businesses.

2.2 The Nature of Innovation

Markusen (2003), writing on regional analysis, notes a lack of clarity in terminology and concepts in the growing regional studies literature. She states that a fuzzy concept is one that has two or more alternative meanings and so cannot be reliably identified or applied by different readers. Difficulty in answering the question "How do I know it when I see it?" suggests fuzziness of concept (2003:702). This difficulty may also be applied to the area of innovation. Frequently theoretical work on the economics of innovation lacks a clear definition of the term itself. Also, there is fuzziness due to the terms used that may or may not address the same phenomena, such as invention, innovation, diffusion, product innovation and process innovation. Since this thesis is concerned with identifying innovation and its sources within business it is critically important to clearly state what innovation is understood to mean for the purpose of this study. This section sets out the meaning of innovation used in this thesis.

2.2.1 The Schumpeterian Trilogy

Schumpeter (1942) identified three stages in the process of technological change, which Stoneman (1998) refers to as the Schumpeterian Trilogy. The first stage is invention, which is the generation of new ideas. The second stage is innovation, which is the extension of inventions into commercially useful products and processes. The third stage is diffusion, which is the spread of new products and processes across the market. The Schumpeterian Trilogy is not a linear process in the sense that each stage requires and must follow the previous stage. It is possible, for example, that the process of diffusion of new products may prompt revisions or improvements in those products. Also, the process of commercialising a new invention may require significant changes in the original idea. There are links in both directions between each stage.

Also, there is not an automatic progression between each stage. Not all inventions or new ideas become new products or processes and not all innovations introduced to the market become diffused. Any one invention may generate many innovations, since new technologies may be put to diverse commercial uses.

The Schumpeterian Trilogy draws a clear distinction between invention and innovation. Stressing the commercial aspect of innovation, Rickards (1985) suggests that innovation is the commercialisation of invention. This suggests that there are products and processes that have been invented but never introduced to the market. As a result it is impossible to measure the incidence or effects of invention. Schumpeter states "as long as they are not carried into practice, inventions are economically irrelevant" (1934:88). For this reason any effective definition of innovation must reflect that the product or process has been introduced to the market.

The third element of the Schumpeterian Trilogy is diffusion, the spread of innovations through an economy. The distinction between this stage and innovation is not as clear as it is between invention and innovation. As businesses adopt products or processes previously introduced by other businesses they question arises as to whether they are themselves innovators. Schmookler (1966) clearly draws a distinction between the activities of the first business to introduce an innovation to the market and those businesses that subsequently adopt that innovation. He states that

> “when an enterprise produces a good or service or uses a method or input that is new to it, it makes a technical change. The first enterprise to make a given technical change is an innovator. Its action is innovation….Another enterprise making the same technical change later is presumably an imitator, and its action, imitation” (Schmookler, 1966:2).

Stoneman (1998), however, challenges this when he presents the concept of global innovation and local innovation. Global innovation is the first introduction of an innovation in an economy or in the world. Local innovation is the first introduction of an innovation in a particular unit of observation such as a business, even where it has already occurred in other units of observation. Clearly, the first local innovator is a global innovator. The adoption by local innovators of the new products or new methods of production represents the spread of the global innovators’ new products or processes through the economy. Kline and Rosenberg seem to suggest that local innovation is an important aspect of the innovation process by stating “the subsequent improvements in an invention after its first introduction may be vastly more important, economically, than the initial availability of the invention in its original form” (1986: 283).

Furthermore, it is unlikely that a business can easily imitate a new product or process. Nelson (1991) contends that technological advance proceeds through an evolutionary process so that where companies’ strategies and associated capabilities differ significantly their patterns of innovation are likely to differ significantly as well. This suggests that businesses may differ significantly in their ability to imitate other businesses' new products or processes. Businesses with similar strategies and core capabilities are in a much better position to imitate and build and learn from each other's work. However, Nelson (1991) contends that since businesses differ in structure and in the personnel that make them up, it is likely that the introduction of new processes or new products to that business requires, for example, changes in existing processes and/or training for personnel.

It can be argued that the process of diffusion can be viewed as a series of acts of innovation by successive businesses and each one business may adapt and/or improve a product or process as they introduce it to their business. According to Kline and Rosenberg (1986) these adaptations and improvements may be commercially important. In this context there would appear no reason to limit a definition of innovation at the business-level to those innovations that are new to the market, or global in Stoneman's (2002) terminology. This means that this thesis is not concerned with the process of diffusion *per se* but rather with innovation in businesses, whether that is global or local.

Storper and Walker state that technological change drives economic growth by transforming both products and processes (1989:51). While Gordon and McCann (2005) state that distinguishing between product and process innovation can be problematic, it is a distinction commonly made in the literature on innovation. Therefore it is useful to consider this distinction at this stage.

2.2.2. Product and Process Innovation

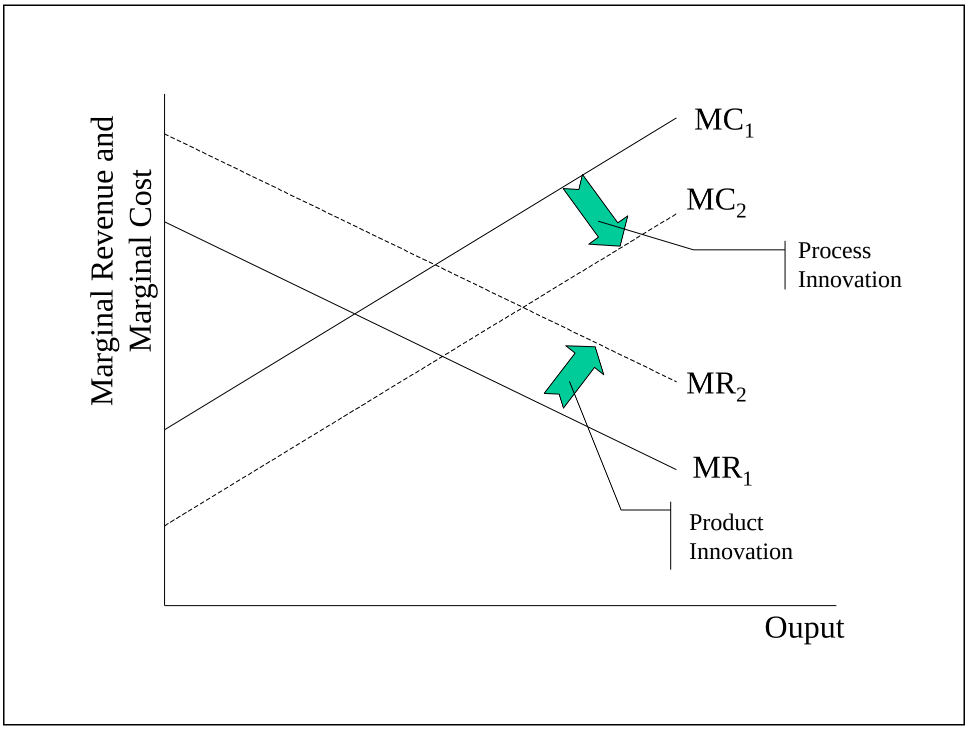
Schumpeter's well-known definition of technological development states that it consists of

> "(1) the introduction of a new good – that is one with which consumers are not yet familiar – or of a new quality of good. (2) The introduction of a new method of production, that is one not yet tested by experience in the branch of manufacture concerned, which need by no means be founded upon a discovery scientifically new, and can also exist in a new way of handling a commodity commercially. (3) The opening of a new market. (4) The conquest of a new source of supply of raw materials or half-manufactured goods (5) The carrying out of a new organisation of any industry" (1934:66).

Of these five elements, only the first necessarily relates to the introduction of a new product or service. The remaining elements relate to new methods of producing or selling an existing good or service. However, the distinction between product and process innovation may not be as clear-cut in practice. As Gordon and McCann (2005) note, product innovation may lead to process innovation and vice versa. For example, new products used as factor inputs or intermediate products may lead to changes in production methods of the user of the new product. Also, the production of new products may require innovations in the method of production.

Baumol (2002) presents a framework for understanding the difference between product and process innovation by considering their effects on a product's supply and demand curves. This is shown graphically in Figure 2.3.

Figure 2.3 The Effect on Supply and Demand of Product and Process Innovation



Source: Baumol (2002:155)

Storper and Walker (1989) state that product innovation is intended to increase the range and quality of goods and services available. This means that a product innovation results in either a new demand or marginal revenue curve, represented by MR_1 in Figure 2.3, or pushing the marginal revenue curve for the affected product to the right, from MR_1 to MR_2. This latter effect would involve the introduction of what

Schumpeter called a “new quality of good” (1934:66). The new good may have additional functionality and so demand increases at any given price.

Baumol (2002) defines a process innovation as one that shifts the supply curve for an existing product or service to the right, from MC_1 to MC_2 in Figure 2.3, by reducing costs at each level of output. At each price level suppliers are willing to supply more output due to lower costs. This is consistent with Storper and Walker’s (1989) view that process innovation is intended to increase the output generated by a given quantity of inputs, that is, to improve the productivity of factors of production. Schumpeter’s (1934) process innovations described at the start of this section can be seen to involve a shift in the supply curve for an existing product. Even the introduction of a product on a new market, the third element of Schumpeter’s definition of innovation, creates a new supply curve. Schumpeter states that product innovation involves the introduction of a product with which consumers are not yet familiar. The opening of new market for an existing product would therefore not mean a new demand curve since consumers in the new market may be aware of the product from other markets.

2.2.3. Defining Innovation for the Purpose of this Thesis

Bringing together Schumpeter’s (1934) elements of innovation, Storper and Walker’s (1989) and Baumol’s (2002) distinction between product and process innovation and the concepts of global and local innovation, product and process can be defined as follows for the purposes of this thesis. Product innovation is the introduction of a new good or service or the introduction of a new quality of existing good or service, which may be new to the market or simply new to a given business. This new quality may include additional features or improved functionality. Process innovation is the implementation of new methods of producing existing goods or providing existing services, which may be new or simply new to a given business. This includes new organisation of an industry or exploiting new sources of supply of inputs, as referred to by Schumpeter (1934:66).

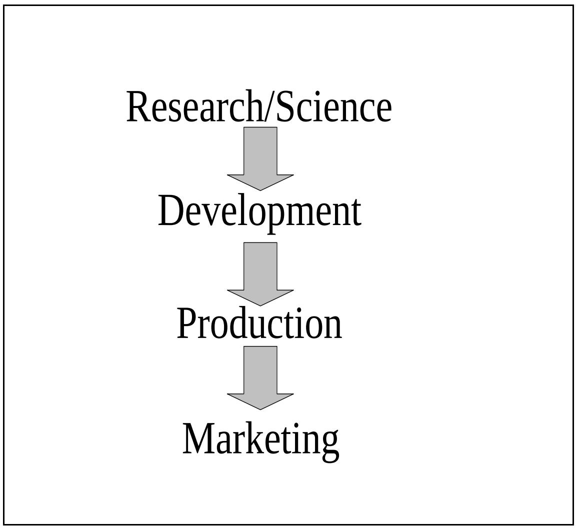
Having clarified the terms used in relation to innovation and how they are treated in this thesis, it is necessary now to consider how innovation occurs in businesses. Two models of the innovation process are presented in the next section.

2.3 Sources of Innovation

In relation to the source of innovation, a distinction is commonly made between science or technology push innovation and demand or market pull innovation. Freeman states that "the simplistic linear model of science and technology 'push' was often dominant" between the end of the Second World War and the 1960s, which meant that "the R&D system was seen as *the* source of innovations" (1995:9 – italics from original).

The linear model of innovation is presented graphically in Figure 2.5 It shows research and science as the starting point for innovation. There is a flow of information in relation to innovation from science to development to production to implementation in the market. In this construct of the process of innovation there is no role for production and marketing functions, except to implement the ideas that emerge from the laboratory. This implies that knowledge residing in the organisation, but outside the R&D department, does not lead to or contribute to the development of new products and processes. For example, process innovation through learning-by-doing is not reflected in the linear model of innovation.

Figure 2.5 The Linear Model of Innovation



Source: Author's own

This model's weakness is the absence of two-way interaction between the agents in the process. Demand-pull innovation does not exist. The model may be considered a simplistic representation of the first two elements of Schumpeter's Trilogy, discussed in Section 2.2.1, invention and innovation. Diffusion is not an aspect of the linear model since within the model the business does not learn from new products already introduced to the market. While the policy implication for innovation of this model is to devote more resources to research, Freeman contends that, historically, committing more resources to research does not guarantee successful innovation and productivity gains (1995:11).

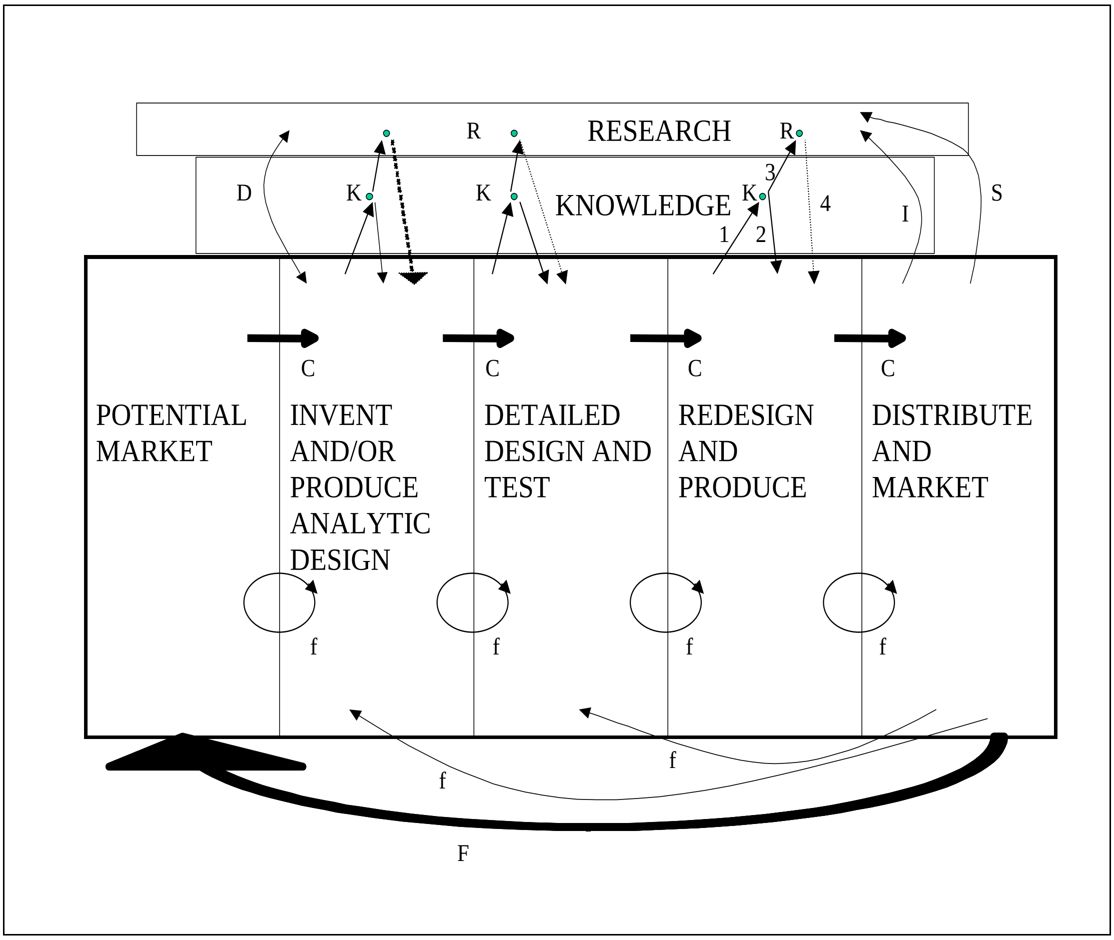
This implies that there must be other sources of innovation not captured by the linear process. There has been a growing acceptance of this since the 1970s. For example, Kline and Rosenberg note that “the use of accumulated knowledge called modern science is essential to modern innovation….but it is not usually the initiating step” (1986; 291). There is more emphasis on two-way interaction between marketing, production and research functions in the innovation process (Kline and Rosenberg, 1986; Von Hippel, 1988; Lundvall, 1988 and 1992; Nelson, 1992).

Kline and Rosenberg (1986) present an alternative model of innovation that captures the complex interactive nature of the innovative process. Their model is presented graphically in Figure 2.6.

The linear model of innovation has one path of activity, while the Chain-Linked Model has five paths. The first of these is called the central chain of innovation and is indicated by the arrows labelled C. This central chain is analogous to the linear model in reverse; the starting point is a potential market for an innovation, rather than basic science or the laboratory. The second path is indicated with f and F and represents feedback links. These paths iterate each step and connect perceived market needs to product and process improvements in subsequent rounds of design. The feedback link indicated by F is considered to be a “particularly important feedback” (1986:290).

This means that experience in the distribution and marketing of new products generates knowledge on other potential markets and/or improvements on existing products and services.

Figure 2.6 The Chain Link Model of Innovation



Source: Kline and Rosenberg (1986:290)

The model recognises that existing technology or knowledge may not be sufficient to enable the development of products and processes to meet identified market needs. A two-stage process, indicated by the arrows labelled K and R, is often required to overcome technological problems. First a solution is sought from the stock of existing knowledge. If this is unsuccessful, then research is needed to derive a solution. This leads to an increase in the stock of knowledge.

An important aspect of this model is the representation of research as coexisting with the innovation process, rather than at the start of the linear model. At each stage in the innovation process, if a technical problem needs to be solved the first source of a solution is known science or the stock of knowledge. The arrows labelled 1 at each stage in Figure 2.6 represent this link. If a solution is found this information is fed back to the innovation process, as represented by arrow 2. Where a solution is not found then research is needed and justified. This is represented by arrow 3 and the solution, if discovered, feeds back to the innovation process, as represented by the broken arrow 4. This does not mean that the research function only contributes to the innovation process when technological difficulties are experienced in identifying customer needs. Research may result in the broadening of technological opportunities and the arrow labelled D represents this technology-push link between new scientific knowledge and the innovation process.

In Kline and Rosenberg's model, the market and science are complementary in the innovation process. The market emerges as a stimulus for innovation, though perceived market needs can be filled only where the associated technical problems can be overcome. New technological opportunities are only commercially exploited where a market use exists. In this context the distinction between science-push and demand-pull is irrelevant.

The strength of the model is its emphasis on the feedback process in the process of innovation. Product specification, development, production, marketing and services functions co-operate to enhance products and processes. Interaction between these function, even informally, may lead to new learning and innovation. This may involve customers' demands being fed back to designers to enhance new products and production operatives realising new ways of organising processes to enhance efficiency.

Kline and Rosenberg present the chain link model as a means of describing process of innovation within a system (1986:275). The boundaries of the system are not defined. If the model is taken to depict the process for a particular innovation, it is not specified which elements of the model are internal and which are external to the business. The implication is that some functions within the model may reside within the business, though others may not. Businesses need not rely on their own R&D effort, but may access knowledge that exists outside the business.

The implication of the science-push and market pull models presented here is that there is more than one source of innovation. An analysis that seeks to identify drivers of innovation in businesses, such as this one, must therefore consider a range of potential drivers. The first of these is the business' own R&D effort. A hypothesis that emerges from the linear model and the central chain of the Chain Link Model is that businesses that engage in research and development (R&D) may be expected, ceteris paribus, to have greater levels of innovation. This innovation may arise from an intellectual breakthrough generated by R&D or indirectly through the benefit to a business' absorptive capacity from performing R&D. The latter effect occurs where performing R&D enhances a business' ability to benefit from interaction with other businesses and organisations. This hypothesis is explored for Irish high-technology businesses in Chapters 6 and 7.

However, an analysis of the drivers of innovation must also include the role of interaction, as depicted in the chain link model and implied in the SECI process of knowledge creation. Subsequent analyses of the sources of innovation in Irish 'high-technology' businesses consider both R&D effort and interaction with other businesses and organisations.

The next section considers in greater detail the role of interaction as a source of knowledge and learning and how knowledge creation and learning are essentially social activities. The section concludes by presenting frameworks that explicitly place interaction at the centre of the innovation process.

2.4 Interaction and the Growth of Knowledge

The basis for a role for interaction as a source of innovation is knowledge spillovers. Through formal or informal, intentional or accidental, market mediated or non-market mediated interaction individuals learn and generate new knowledge. Both Kline and Rosenberg's (1986) chain-link model of innovation and Nonaka et al's (2001) SECI framework for knowledge creation indicate an important role for interaction between individuals in the generation of knowledge for innovation.

2.4.1 The Importance of Interaction in the Market System

Loasby (1993) also contends that the processes of hypothesising, testing and criticising that leads to the growth of knowledge is inefficient if carried out by individuals in isolation. This is due to the importance of the social context within which knowledge creation occurs. Popper (1972) argues that an orderly process of testing requires a set of rules or conventions, referred to as the institutional framework within which knowledge may be effectively sought. The social nature of the search for knowledge or learning means that each individual's frameworks must be compatible with others and resistant to change. Lakatos (1970) argues that the growth of knowledge is both conditioned by and modifies the institutional setting within which it occurs. He states that this process is best characterised as interpersonal, rather than personal.

Loasby (1993) characterises the introduction by a business of a new product or process to the market as a system of conjecture, criticism and testing. What is tested in the market is the set of hypotheses offered by that organisation, in the form of new products, and the capacity of that organisation to offer hypotheses which meet with corroboration. Corroboration means that consumers purchase the businesses products.

This means that it is a test of fitness relative to what is on offer at the time both as a substitute and as a complement.

Each business's knowledge of the market experiments of its rivals is critical to the advance of knowledge. Theories and policies are continuously tested and revised in a process of continued experimentation within the market system. Relationships between the business and its customers and suppliers are important with regard to the effect they have on structuring the growth of knowledge. This process of testing requires interaction between producers and consumers, as consumer behaviour is reflected in subsequent experiments or new product launches. Richardson (1972) states that businesses engage in a variety of technical, social and legal links that evolve over time. Businesses invest in relationships with customers and suppliers, building up market assets, such as reputations and goodwill. Transactions within a network, either a market, business or scientific community, depend on and generate new knowledge.

2.4.2. Interactive Learning

Interaction is also critical for the growth of knowledge and innovation is because of the social aspect of learning. Lundvall (1988), introducing the concept of innovation systems, places learning at the heart of the process of innovation. He argues that, since learning is interactive and social in nature, the process of innovation must be looked at in a social context. The economic structure and the institutional set-up create a framework for and strongly influence and affect the processes of learning and through this affect the processes of innovation.

Learning occurs due to R&D efforts, though this is not the only type of learning that is important for a business's innovation performance. Learning also occurs with routine activities in production, distribution and consumption and these in turn produce inputs to the innovation process. Kline and Rosenberg's (1986) chain linked model of innovation, presented in Section 2.3, presents a similar structure where there are feedback loops between functions of the business. The knowledge and insights of, for example, workers, production engineers and sales executives, can influence the direction of innovative effort and so are crucial inputs into the process of innovation.

Learning is an important aspect of interaction between producers and users of innovation (von Hippel, 1988). There are three elements to learning that facilitate interaction between producers and users of knowledge and innovation (Lundvall, 1992:59). These are technical, communicative and social. Technical learning differs for users and producers of innovation. Users of innovation go through a three-step process involving awareness of new technologies, understanding of the potential usefulness of these technologies and developing know-how in relation to these technologies. Each step is likely to involve interaction with the producer of the innovation. Producers of innovation also go through a three-step process in technical learning. The first step is awareness of user needs. Second, the producer must understand how its competencies can be used or adapted to produce the technologies required by user. Third, the producer seeks feedback from the user on the effectiveness of the innovation and difficulties encountered in its use.

Interaction is a crucial element in each of the steps taken by users and producers. However, in order to communicate, both must learn a technical code. This is communicative learning. The purpose of this learning is to facilitate the transmission of ideas and information. This learning may be based on codified knowledge and/or tacit knowledge, or a combination of both, and is facilitated by the development of an institutional framework. This framework underpins the third aspect of interactive learning, which is social learning.

There may be an imbalance in the technical knowledge of users and producers of innovation. This could result in the potential for opportunistic behaviour. A lack of trust inhibits technical and communicative learning, so users and producers must learn the social aspects of interaction, which is the basis of social learning. This can only be acquired through shared experiences and interaction.

These arguments outline a critical role for interaction in the growth of knowledge and innovation. They suggest a hypothesis, explored in Chapters 5, 6 and 7 for Irish high-technology businesses, that businesses that interact with external organisations for innovation may be expected, ceteris paribus, to have a greater level of innovation. This thesis examines whether innovation in Irish ‘high-technology’ businesses is positively affected by the incidence and frequency of interaction between businesses and other organisations. It also tests the relative importance of interaction as a source of knowledge for innovation in these businesses.

The next section considers the effect on interaction of geographical proximity and agglomeration. It is concerned with whether interaction and knowledge spillovers are geographically bounded or, at least, facilitated by proximity.

2.5 Spatial Aspects of Interaction for Innovation

The previous section presents the theoretical bases for interaction as a source of knowledge, though the discussion has so far not considered the effect of geographical proximity on the frequency or effectiveness of interaction. Fujita, Krugman and Venables (1999) contend that, while mainstream economics had earlier neglected the spatial aspects of economic activity, since the start of the 1990s there is a strong growth in theoretical and empirical literature concerned with geographical aspects. This body of work has been termed new economic geography (Krugman, 1991 and 1998; Martin, 2001; Fujita et al, 1999). The defining issue of this new economic geography is “the need to explain concentrations of population and of economic activity” (Fujita et al, 1999:4). This section considers why innovation, as well as economic activity generally, tends to concentrate geographically. First, internal and external agglomeration economies are presented based on a categorisation by Parr (2002). Second, conflicting views on the relative importance of agglomeration and geographical proximity for knowledge spillovers are explored. The final part of this section presents frameworks suggested to explain how business-level innovation can be encouraged by spatially bounded interaction with other businesses and organisations.

2.5.1 Agglomeration Economies

Parr (2002) warns that vagueness surrounds the concept of agglomeration economies, and that frequently the term is used in such a way as to result in misspecification or misinterpretation. He draws together work on various aspects of agglomeration and business location to present a clear statement of the types and sources of agglomeration economies. The following section draws on Parr's specification.

Agglomeration economies are cost savings to the individual business due to its location. Parr identifies internal and external agglomeration economies, and these are set out in Table 2.1.

Table 2.1 – Types of Agglomeration Economies to the Business

Dimension	**Spatially Constrained Economies Internal to the Business**	**Spatially Constrained Economies External to the Business**
Scale	Economies of Scale	Localisation Economies
Scope	Economies of Scope	Urbanisation Economies
Complexity	Economies of Complexity	Activity-Complex Economies

Source: Parr (2002:154)

Internal Agglomeration Economies

The first type of internal agglomeration economy is economies of scale. These are cost savings to the business from increase in the size of the business, so that long-run average cost decreases as output increases. Economies of scale exist where

$$TC(\delta Q_x) < \delta TC(Q_x)$$

where $TC(Q_x)$ is the total cost of producing a given output of good x. If the output of good x increases by a given multiple, δ, economies of scale exist if the total cost of producing that higher level of output increases by a multiple less than δ. This would result in a lower average cost at the higher level of output. Parr notes that economies of scale do not necessarily result in agglomeration, but where economies of scale require the concentration of production at a given location then these spatially bounded internal economies of scale may be considered one type of agglomeration economy (2002:153).

The second type of internal agglomeration economy arises due to economies of scope. Economies of scope exist where a business achieves lower average cost as it increases the variety of goods or services it produces. A production process is said to exhibit economies of scope where:

$$TC(Q_x, Q_y) < TC(Q_x, 0) + TC(0, Q_y)$$

where $TC(Q_x, Q_y)$ is the total cost of producing a given output of product x and a given output of product y. $TC(Q_x, 0)$ is the total cost of producing a given output of product x and zero output of product y. $TC(0, Q_y)$ is the total cost of producing zero output of product x and a given output of product y. Economies of scope exist where one business can produce a given output of both products at a lower cost than two businesses producing the same level of output of each product separately. Panzar and Willig (1981) state that economies of scope arise from sharable inputs that, once procured for the production of one good, are available for the production of another good. These shared inputs may include indivisible equipment or a factory building and human capital that can be applied to the production of more than one output (Panzer and Willig, 1981:269). Just as with economies of scale, scope economies do not necessarily result in agglomeration economies. However, economies of scope may require the production of different products at a given location, for example where they are based on the sharing of immobile inputs such as machinery or the need for employees to be located in the same place to learn from different production processes. These spatially bounded internal economies of scope may be considered another type of agglomeration economy (Parr, 2002:155).

Economies of complexity, the third type of internal agglomeration economy, exist where a single business achieves a lower total cost of producing a given output by undertaking discrete stages of the production process than would be the case if separate businesses undertook these stages. These stages may be sequential, where the production processes occur in succession, or convergent, where various manufactured inputs are drawn together for final assembly. Businesses may benefit from integration of the stages of production without those stages being co-located. However, there may be spatial aspects to these economies of complexity, for example where geographical proximity reduces handling and/or transportation costs or facilitates improved quality control. In these cases, the complexity of the production process provides the incentive for geographical concentration.

While the basis of internal economies of agglomeration presented by Parr (2002) is reduced cost through shared inputs that require co-location, it is possible that internal agglomeration economies may encourage knowledge spillovers from one business in a group to another business within the same group. This interaction may become more frequent where group businesses are located closer to each other. This issue may be of particular concern in an Irish context. The Irish economy is characterised by high levels of foreign direct investment. A key motivation behind government efforts to attract foreign multinationals to establish Irish operations is the potential for knowledge spillovers from these operations to indigenous businesses. The extent to which the internal economies of scale, scope and complexity in the multinationals investing in Ireland are independent of location will affect the ability of Irish operations to benefit from intra-group knowledge spillovers. The effect on innovation of interaction with other group businesses and the importance of proximity for that interaction is estimated later in the study.

External Agglomeration Economies

Parr (2002:157) states that, typically, internal economies of agglomeration do not result in major concentrations of economic activity. External agglomeration economies are more important in explaining this phenomenon. These economies are beyond the control of individual businesses and depend on the actions of other businesses. Parr (2002) identifies three types of external agglomeration economies. These are localisation economies, urbanisation economies and activity-complex economies.

Localisation Economies

Localisation economies are advantages to individual businesses arising from the common location of independent businesses in the same industry. There are numerous examples of geographic concentrations of businesses in the same or related industries, such as semiconductor businesses in Silicon Valley (Saxenian, 1990) and financial services businesses in the City of London (Gordon and McCann, 2005). Localisation economies are derived from three sources, identified by Marshall (1920). These are information spillovers, the availability of a local skilled labour pool and the growth of subsidiary and specialised services and trades.

Marshall explains information spillovers as the "advantages which people following the same skilled trade get from near neighbourhood to one another. The mysteries of the trade become no mysteries; but are as it were in the air" (1920:271). This suggests that information spillovers are market or non-market mediated transfers of knowledge that occur from face to face contact between individuals from different businesses. Closer geographic proximity facilitates this transfer because it increases the frequency of contact and also encourages trust between the individuals.

Marshall (1920) also identified a local skilled labour pool as a source of localisation economy. Employers are attracted to locations where there is a supply of labour with the skills required for their business. This reduces labour acquisition costs by reducing search costs and the costs of training new employees. There is also an incentive for risk-averse workers to concentrate in a particular location where there are several businesses in the same or related industries that may require their specific skills. If one business fails there are alternative businesses with which to gain employment.

Marshall's third source of localisation economy is the growth of subsidiary services and/or trades. Subsidiary services or trades refer to specialist inputs or services provided to a number of businesses clustered geographically. Where many businesses in the same industry are concentrated geographically these specialist inputs may be provided to the group in a more efficient and cost-effective way than if the businesses in the industry are geographically dispersed. An example of this is the presence of specialised legal firms to service the needs of financial institutions with the City of London or the presence of businesses providing clean-room technology services to microprocessor businesses in Silicon Valley.

Marshallian sources of agglomeration economies are echoed in Porter's (1990 and 1998) cluster framework. Porter describes a cluster as a "geographic concentration of interconnected companies and institutions in a particular field" (1998:78). Similarly to Marshall's description of localisation advantages, Porter states that clusters feature suppliers of specialised inputs and businesses that are connected through shared skills needs and technologies. One significant difference between Marshall's and Porter's frameworks is the importance in Porter's clusters of competition between businesses within the region. While Marshall does not refer to the businesses located in "near neighbourhood" (1920:271) competing it could be inferred that since a significant proportion of trade in Marshall's time was local, competition was implied. However, Porter's clusters are characterised by the high level of rivalry between businesses within the cluster which encourages each business to continually strive to innovate and improve.

Within both Marshall's and Porter's frameworks, knowledge spillovers is an important agglomerating influence. This is based on the idea that geographical proximity makes interaction between businesses and other institutions easier and more efficient since trust can be established quicker. A number of hypotheses are suggested by these frameworks. The first of these is greater interaction between a given business and other businesses and institutions leads to higher levels of innovation in that business. Second, the frequency of interaction among businesses and between businesses and other institutions increases with the geographic proximity between those businesses and institutions. The businesses and institutions with which businesses interact for innovation are identified from empirical studies discussed in Chapter 3, though Porter (1990) indicates that the elements within a cluster include suppliers, customers, competitors, third-level institutes and public institutions that support the workings of the cluster. The extent of interaction with each of these businesses and organisations, along with other group companies that generate internal agglomeration economies, will be examined in subsequent analyses.

Urbanisation Economies

The second type of external agglomeration economy is urbanisation economies. These are advantages to individual businesses arising from the common location of businesses from different and unrelated industries. In this situation businesses benefit from shared inputs such as transportation services, public utilities and business and commercial services. While localisation economies suggest that businesses benefit from specialisation of businesses within a specific area, urbanisation economies suggest that businesses benefit from diversity within the area.

Gordon and McCann suggest that these “differences in the geography of creativity and entrepreneurship” (2005:528) are based on a diversity of skills, ideas and cultures that enable new combinations of knowledge to emerge, a permissive environment that allows different and unorthodox ideas to emerge and a highly competitive environment, including discriminating consumers of new products. Jacobs (1969) and Glaeser et al (1992) argue that more diverse cities grow faster than specialised cities. This is based on the existence of cross-sectoral knowledge spillovers, where businesses identify new products and processes and new uses for existing products and processes in businesses in different sectors.

Florida argues that creativity, which is the ability to create meaningful new forms, is now “the *decisive* source of competitive advantage” for cities and regions (2002:5 – italics in original). Creativity is a function of a more permissive and open-minded environment, which enables greater acceptance of new and different ideas. Florida (2002) argues that innovation in urban areas is positively associated with the existence of a “creative class”.

Finally, urbanisation economies may be driven by the proximity of a large number of consumers which enables businesses to more easily introduce products to the market place and more quickly receive feedback from customers (Hall, 1998). The proximity of a sizeable market place enables businesses to experiment with products and processes without incurring large transportation costs.

Activity-Complex Economies

The third type of external agglomeration economy is activity-complex economies. These economies result from the common location of a set of businesses that operate at different stages of a production chain. Parr (2002:161) presents two simple examples to explain the nature of these economies. These are the example of a business that is situated at the location of its customer business, representing a forward linkage in the production chain, and a business that is situated at the location of its supplier business, representing a backward linkage in the production chain. The rationale for a business’s location decision in these examples may extend beyond transportation cost savings and arise from the complexity of the production process.

Where this complexity is combined with low transaction costs there is little incentive for a business to vertically integrate along the production chain. The extent to which the cost saving achieved by these businesses requires the concentration of activity at a given location then these spatially bounded external economies may be considered a type of external agglomeration economy.

As noted earlier, this study considers the effect of interaction with suppliers and customers, along with other potential interaction agents, on a business' innovation activity. However, there is little value in examining whether these interactions are characterised as localisation or activity-complex economies from an innovation perspective. What is relevant from the perspective of this study is whether and to what extent interaction occurs, its effect on innovation and whether it is geographically bounded. This study is not directly concerned with the complexity of the relationships between suppliers and customers along the supply chain.

2.5.2. Knowledge Spillovers as a Source of Agglomeration

Malmberg and Maskell (2002) distinguish between traditional approaches to agglomeration which are based on cost reduction and recent approaches which are based on knowledge spillovers. The traditional approaches are the existence of a localised skilled labour force, which reduces search costs for businesses in finding labour, and the availability of specialised intermediate inputs, which can be provided at a lower cost due to market size effects.

Krugman (1998) argues that new economic geography is characterised by its choice of traditional, cost-based sources of agglomeration as the basis for analysis. This choice is based on strategic modelling considerations (1998:9). Localised knowledge spillovers are placed to one side as a focus of analysis by new economic geography in favour of forces that "are more amenable to analysis" (1998:9). Krugman even goes so far as to argue that economists should not attempt to measure knowledge spillovers as a centrifugal force since "knowledge flows are invisible, they leave no paper trail by which they may be measured and tracked" (1993:53).

The difficulties encountered in identifying appropriate measures for innovative output and the extent of business interaction, which are discussed in detail in Chapter 3, would support Krugman's contention on the problems of estimating the effect of knowledge flows. However, knowledge spillovers are a critical element in several approaches to explaining regional differences in innovation activity. The argument that knowledge spillovers are spatially bounded has been encapsulated by Glaesar et al who, in analysing the role of regional specialisation for the growth of cities, argue that "intellectual breakthroughs must cross hallways and streets more easily than oceans and continents" (1992:1127).

The idea that knowledge spillovers are spatially bounded has also emerged from models developed to explain aspects of the geographical concentration of economic activity. The first of these is the Growth Pole Model (Perroux, 1955 and 1988), a survey of which is presented in Parr (1999). The basis of this model is that large business or public location-specific investment can generate local growth. Local businesses, because of their proximity, increase sales to the new investor leading to growth in economic activity in the geographical area of the investment. While the benefits to the local economy are largely based on the market-based supply of goods and services, market-based or external knowledge spillovers from the large public or private investment to smaller local businesses are also a significant benefit to the area in which the investment is located.

The Product Cycle Model, based on the product life cycle theory of Vernon (1966), contends that businesses separate activities by location based on the stage of development of the product. Businesses tend to locate knowledge-sensitive activities, such as research and development and the production of technologically new products, in places where important knowledge can be accessed more easily. This tends to favour geographical concentration of activity for products and processes based on new, non-standardised knowledge. These are products and processes at the start of their life cycle. Over time, production techniques and products tend to become better understood and the knowledge required is increasingly standardised and more likely to be codified. In this situation the lower input costs in geographically peripheral areas outweigh the need for access to knowledge. McCann (2001) notes that this means that a qualitative distinction may exist between economic activity at the economic centre and periphery of geographical areas.

The growth pole model and the product life cycle model stress the role played by large businesses in generating growth in regions. The location decisions made by individual large businesses create the conditions for growth in particular regions. Other approaches stress the importance of concentrations of smaller businesses that interact and co-operate for innovation within a localised area, surveyed in Moulaert and Sekia (2003). These include Innovative Milieu, Industrial Districts, Regional Innovation Systems, New Industrial Spaces and Learning Regions. Porter's (1990 and 1998) clusters framework, which is discussed in Section 2.5.1, also stresses the importance of geographically concentrated businesses engaged in competition and co-operation as a driver of innovation within businesses.

These frameworks stress the importance of interaction between businesses and institutions within the region as a source of innovation. The institutional set-up, including innovation-supporting agencies and academic researchers, facilitates sharing of knowledge between businesses and institutions and/or accessing knowledge that is available externally within the region. They suggest a hypothesis that a business will interact more frequently with interaction agents more proximate to it and that a business that interacts for innovation over shorter distances and/or is located in an urban area will, ceteris paribus, have greater levels of innovation.

To explore these hypotheses, despite the difficulties identified by Krugman (1988) in mapping knowledge spillovers and their effects on business-level innovation, tools to identify, measure and estimate these flows must be explored. The approaches adopted in empirical innovation studies are examined in the next Chapter and these approaches inform the method used in this thesis to explore interaction as a source of innovation in Irish 'high-technology' businesses.

2.6 Conclusion: Hypotheses and Next Steps

The literature review presented here raises a number of hypotheses relating to the factors that drive business-level innovation activity. These hypotheses have been referred to briefly throughout this Chapter and are summarised in this section. They are tested empirically for Irish high-technology businesses; the results of which are presented in Chapters five to seven.

First, ceteris paribus, businesses that engage in research and development (R&D) may be expected to have greater levels of innovation. This refers not only to the research element of R&D, which is concerned with developing new technologies or seeking new scientific breakthroughs, but also with the development element of R&D. This latter element is concerned with improving existing products and processes to meet market needs. Of course, not all R&D activity will result in a commercially exploitable product and process, though performing R&D enables businesses to identify new technological opportunities and also builds absorptive capacity to enable businesses to identify, evaluate and exploit knowledge in the business' environment. In this context, R&D may contribute to innovation output, new products and services and new processes, directly through scientific breakthrough or indirectly by improving the opportunities for and efficacy of interaction with all interaction agents, but particularly academic-based researchers and other research organisations.

It is noted in Sections 2.2 and 2.3 that R&D is not the only source of knowledge for business innovation. Knowledge creation and learning is a social and interactive phenomenon. This implies that knowledge for innovation may emerge through interaction between businesses and between businesses and other organisations. Interaction may result in knowledge for innovation emerging serendipitously or interaction may be intentionally aimed at generating knowledge for innovation, for example in relation to contracting university research or business joint ventures. However, whether intentional or unintentional, interaction enables businesses to access external knowledge, particularly tacit knowledge. It may the case that accessing external knowledge complements internal R&D activity. However, particularly in smaller businesses, resources may not be available for R&D and external interaction is the source of knowledge for innovation. Businesses that interact with external organisations for innovation may be expected, ceteris paribus, to be more innovative, since they are likely to have greater awareness of, for example, customer needs, supplier capabilities and academic research.

If interaction is an important source of knowledge for innovation it may be expected that businesses within urban areas or located close to other similar businesses are more innovative than remote businesses. Geographic proximity facilitates easier and more frequent face-to-face interaction, which enables knowledge to diffuse more quickly. This may be particularly important in businesses engaged in sectors based on new technologies where much of the knowledge remains tacit. Knowledge spillovers have been identified as one source of localisation economies, which are derived from the common location of businesses in the same or similar sectors. A diverse, permissive and competitive environment, which facilitates and encourages new combinations of knowledge and ideas is one source of urbanisation economies. These are benefits arising from a business' location with an urban area. While economic activity does tend to concentrate geographically, it is difficult to distinguish the extent to which this is due to the availability of knowledge spillovers or the potential of learning from other businesses in other sectors rather than other cost, labour market or market factors. It may be expected that businesses located closer to other group companies, customers, suppliers, competitors, academic-based researchers and innovation-supporting agencies will interact for innovation more frequently than more distant businesses. Also, ceteris paribus, if a business interacts over shorter geographic distances and/or is located within an urban area, this should result in greater levels of innovation within that business.

While the literature discussed in this Chapter suggest a positive relationship between geographic proximity and the frequency and efficacy of interaction for innovation, the particular characteristics of the Irish economy mean that such a relationship may not be appropriate. The importance of foreign multinationals to the Irish economy, the limited size of the domestic market and the importance of international selling raise questions about the degree of local or regional interaction with customers, suppliers and competitors that may reasonably be expected in the Irish case. This thesis makes an important contribution to the literature on geographic proximity and interaction for innovation by measuring these effects for a small open economy such as Ireland.

These hypotheses are tested in subsequent Chapters using new survey data of Irish high-technology businesses. The methods used to test the hypotheses are based on methods used in other related innovation studies. Chapter 3 presents a survey of relevant empirical literature, which educates the choice of indicators and measures used to model and estimate the factors that drive innovation in Irish high-technology businesses. Chapter 3 begins by reviewing empirical approaches to modelling the process of innovation. Measures of product and process innovation output and the factors that determine the level of innovation, including R&D effort, interaction and business characteristics are presented. Alternative approaches to testing the effect of spatial agglomeration and proximity on interaction and innovation are also set out. These inform the choice of indicators and methods used to model and test the drivers of the innovation in Irish high-technology businesses.

Chapter 4 presents the methodology adopted in this thesis to generate survey data used to test the hypotheses set out above. The Chapter sets out the method used to generate a sample frame of businesses in Irish high-technology sectors. The design of the survey instrument and the data collection process are discussed, followed by an analysis of the representativeness of the sample frame and item and survey non-response. The data generated by the survey are presented first in Chapter 5. This contains descriptive statistical analysis of the survey data. The level of product and process innovation output, R&D activity, the incidence and frequency of interaction for product and process innovation across the range of potential interaction agents are analysed by sector, indigenous and foreign ownership, business age and business size.

Chapter 6 presents an innovation production function that models innovation output in a business as a function of R&D effort within the business and interaction with other businesses and institutions. Appropriate statistical techniques are used to estimate the relative importance of R&D and interaction for innovation with a range of interaction agents for innovation output. At the end of Chapter 6 the results of these estimations are summarised and their implications for Irish innovation and enterprise policies are presented in detail. Further analysis, based on the survey data, reported in Chapter 7 focuses on the spatial dispersion of interaction for innovation between Ireland's high-technology businesses and their interaction agents. The effect of agglomeration on innovation output, using secondary data sources to measure agglomeration, is also estimated and these estimations are reported in Chapter 7 along with policy implications. Finally, Chapter 8, draws together the summary findings, conclusions and policy implications from the previous three Chapters.

CHAPTER 3: EMPIRICAL STUDIES ON THE DETERMINATION OF INNOVATION PERFORMANCE

The conceptual framework outlined in Chapter 2 indicates a positive role for interaction among businesses and between businesses and other organisations in explaining businesses' innovation performance and that such interaction may be facilitated by geographical proximity. This interaction leads to knowledge spillovers, which may be spatially bounded, and the potential for greater levels of innovation within businesses. Having outlined these conceptual frameworks and theories, this Chapter presents a survey of empirical literature on innovation and the factors that influence the relative success of innovative activity. The objective of this Chapter is to educate the methods used in subsequent Chapters to examine the drivers of innovation in Irish ‘high-technology’ businesses.

The Chapter is structured as follows. First, approaches to the measurement of business-level innovation performance are presented. Studies of innovation have most frequently used patent statistics as their measure of businesses’ innovation performance. Difficulties with this approach are analysed and alternatives presented. Having considered how innovation is measured, the subsequent sections consider the drivers of innovation at the business level. Section 3.2 discusses evidence on the relationship between research and development (R&D) and innovation output, focusing in particular on in-company R&D. As noted in the Section 2.4, interaction is also an important potential source of knowledge for innovation and Section 3.3 discusses empirical studies of interaction for innovation between businesses and between business, universities and innovation-supporting agencies. In Section 3.4

interaction is considered from a spatial perspective, examining whether there is evidence to support the existence of geographically bounded knowledge spillovers. This section concludes by considering the difficulties associated with using co-location as a measure of geographical proximity.

Section 3.5 reviews Irish studies of knowledge spillovers and interaction as a driver of innovation. Section 3.6 concludes.

3.1 Measuring Innovation

Kuznets (1962) identified a lack of meaningful measures of innovation inputs and outputs as the greatest obstacle to understanding the role of innovation in business and economic development. While there have been significant advances in the availability of innovation statistics in the years since Kuznets made that observation, innovation studies are still constrained by the lack of a widely accepted measure of innovation in business. This is partly due to the difficulty of defining innovation itself and partly due to the difficulty of finding a measure that encapsulates innovation across all sectors and business activities.

Davelaar and Nijkamp (1989) note several indicators of innovation inputs and outputs. The former includes the number of skilled workers and R&D expenditure and the latter includes patent counts or the number of new products. A significant obstacle faced by studies of innovation is that there is no single accepted output measure. Advances in economically useful knowledge may be manifested in several ways, such as the development of new products, new manufacturing processes, new service methods, new markets or new ways of organising a business. Product innovation is the most commonly used measure of the innovative output of businesses in empirical work to date.

Table 3.1 sets out the range of indicators used to measure innovation output at business level in empirical studies on innovation. Output indicators are concerned with counts of new products or new processes, in some instances controlling for characteristics like business size or resources dedicated to research and development. Indicators of the extent of diffusion of knowledge, a critical element of innovation, have relied on the number of citations contained in patent statistics for previous innovations and the identification by private business researchers of key academic research influences. These measures have been used to examine the extent to which innovation in businesses is affected by interaction and the degree to which that interaction is spatially bounded.

Table 3.1 – Measures of Innovative Activity
Output Measures • Number of Patents (Jaffe, 1989; Malerba and Orsenigo, 1995; Breschi, 2000; Ceh, 2001; Fritsch, 2002) • Number of Patents per Dollar spent on R&D (Jaffe, 1986) • Innovations identified in U.S. trade and engineering journals (Acs and Audretsch, 1987 and 1988; Acs et al, 1992; Anselin et al, 2000) • Presence or otherwise of new products or processes (Yes/No) (Harris and Trainor, 1995; Love et al, 1996; Roper, 2001; Love and Roper, 2001b; Fritsch, 2002; Tether, 2002; Becker and Dietz, 2004) • Number of new products or processes introduced (Roper, 2001; Love and Roper, 2001b) • Proportion of turnover derived from new products introduced in a specified time frame (MacPherson, 1998; Roper, 2001; Love and Roper, 2001b) • Number of new or improved products per 100 employees (Roper, 2001; Love and Roper, 2001b) • Number of Products on the market at a given time (Zucker, Darby and Armstrong, 1998) • Number of products in Development (Zucker, Darby and Armstrong, 1998) • Number of new products as a proportion of the total number of products in the firm’s product base (Freel, 2000a and 2000b)
Diffusion Measures • Number of Patent Citations (Jaffe et al, 1993) • Identification of Academic Researchers Influencing Corporate Innovation (Mansfield, 1993)

3.1.1 Patents as Indicators of Innovative Activity

Griliches (1990) presents a survey of patent statistics as economic indicators. While recognising the limitations of patents statistics as a measure of innovative activity, he states that they remain a "unique resource for the analysis of the process of technical change. Nothing else even comes close in the quantity of available data, accessibility, and the potential industrial, organisational and technological data" (1990:1702)

Largely for these reasons, patent statistics were the most common source of measurement of innovative output throughout the 1980s an 1990s. Bound et al (1984), Hall et al (1986) and Griliches, Pakes and Hall (1987) use patents as indicators of innovation output by businesses. Jaffe, modelling spillovers to businesses from university R&D, utilises corporate patents registered at the U.S. patent office as a "proxy for new economically useful knowledge" (1989:958). Malerba and Orsenigo (1995) also use corporate patent counts as a measure of innovative activity. Their study, based on data for the period from 1968-1986, compares patterns of innovation across a range of variables including business size and concentration of innovative activities within industries. Patent statistics are used, despite acknowledged problems, because they are an homogenous measure of invention across countries and are available over a long time series. Ceh (2001), examining the dispersal of innovation across the U.S., uses patents to compare regions. Sonn and Storper (2003) also use patents, in particular patent citations, to explore the extent to which geographical proximity between innovators may be important for technological innovation. Patents have also been used in European studies. Breschi (2000) uses patent data from the

European Patent Office to examine the spatial patterns of innovation across industries and countries. Fischer and Varga (2003), exploring the extent to which innovation in Austrian businesses is influenced by university research, use patents as an indicator of the output of business' innovative activity.

The degree of information contained in patent applications means that patent citations have been used to measure diffusion of knowledge and innovation. Jaffe et al (1993) use patent statistics to measure the extent to which the diffusion of innovation is geographically bounded. U.S. patent statistics include detailed geographic information about the patent holder and also citations of previous related patents. The granting of a patent implies that the invention to which the patent refers represents new knowledge over and above the previous state of knowledge, as represented by the earlier patent cited. As Jaffe et al state "a citation of Patent X by Patent Y means that X represents a piece of previously existing knowledge upon which Y builds" (1993:580).

Patent statistics are a popular measure of innovative activity because of their availability and accessibility. Furthermore they share generally common international standards and so facilitate international comparison. This is particularly useful for policy makers to benchmark national performance. Despite their common use, there are a number of difficulties presented by patents as measures of the output of innovative effort (Griliches et al, 1987:106, Cohen and Levin 1989:1063, Griliches, 1990 and Watanabe et al, 2001). In some cases product innovation may lead to process innovation, as a new product invention by one business may present process improvement opportunities in businesses using that invention. However, by their nature patents only measure product innovation. Even as a measure of product innovation or invention patent counts are problematic. First, not all inventions are patentable. Second, not all inventions that are patentable are patented. Industries and technologies may be characterised by different propensities to patent. These propensities are conditioned by the trade-off between patenting and secrecy. The registration of patents makes technological information public, when it may not be available otherwise. Where technological information cannot be determined by means other than patent details, such as reverse engineering, secrecy may be preferred to patents. Alternatively, patents may be preferred to secrecy in the same circumstances where they are required as a signal of a business's technological competence to customers or suppliers of capital (Cohen and Levin, 1989:1063). Third, patent data does not enable a distinction to be made between radical and incremental inventions, in either technological terms or economic terms.

3.1.2. Alternatives to Patents as Measures of Innovation

The shortcomings of patents as a measure of innovation set out above have led to alternative approaches in empirical innovation literature. Acs and Audretsch (1987 and 1988), Acs, Audretsch and Feldman (1992) and Anselin, Varga and Acs (2000) use a database of innovations created by the U.S. Small Business Administration. This is constructed from lists of new products and processes announced in technology, engineering and trade journals in 1982. Innovation for the purpose of this database is defined as a process that results in the introduction of a new product, process or service to the market (Acs and Audretsch, 1988:679). While the definition includes process innovations, it is found that the journals tend to "capture mainly product innovations" (1988:680). This is because most businesses use the listing of new products in these journals as a form of advertising or a signal of technological capability. Acs et al (1992) argue that this data provides a more comprehensive measure of innovative activity than patent statistics. This is because the data includes inventions that are not patented but are introduced to the market and excludes inventions that are patented but did not subsequently appear in the market. However, the data does not seem to have been collated for any country or year other than for the U.S. in 1982. It is indicative, however, of an approach that relies more on businesses indicating themselves whether they have introduced new innovations, rather than using official innovation statistics.

This has been taken further by subsequent surveys of business level innovation, where businesses are asked to indicate themselves whether they have introduced new products and processes. Through the 1990s and the current decade, survey data has become more common. Empirical studies that use survey data are referred to in subsequent sections of this Chapter but examples include Kleinknecht and Poot (1992), Appleyard (1996), Andreosso-O'Callaghan (2000), Roper (2001), Fritsch (2002), Hewitt-Dundas et al (2002), Freel (2003), Becker and Dietz (2004) and McCann and Simonen (2006)

The surveys on which these studies are based ask businesses to indicate whether they have introduced new products or new processes over a specific period of time. Although Harris and Trainor (1995), in analysing the determinants of innovation performance of businesses in Northern Ireland, use a survey-based approach they measure innovation output by asking businesses to indicate whether they had patented a product or process innovation in the ten years to 1991. This approach does not overcome the difficulties associated with patents as a measure of innovation output.

The most common survey-based measure of innovation output has been a binary variable taking a value of one if the business indicates that it has introduced a new product or process in a specified period of time (Roper, 2001; Love and Roper, 2001; Freel, 2003 and Gordon and McCann, 2005). A significant benefit of this approach to measuring innovation output is that it facilitates a broader definition of innovation than may be the case using official patent statistics, which may be concentrated on technological innovation. A survey approach also allows alternative indicators of the intensity or success of innovation to be measured. For instance, Roper (2001) identifies four dimensions of the extent and success of product and process innovation. In a survey of businesses in the Republic and Northern Ireland respondents were asked to indicate whether their business had introduced any new or improved products or processes over a three-year period. The result of this question would be a ‘yes or no’ response. Second, the businesses were asked to specify the number of new or improved products they introduced over the same three-year period. Third the businesses are asked to indicate the proportion of their turnover in the final year of the survey period obtained from products introduced or improved significantly in the three-year period. The first two indicators measure the extent to which the business is engaged in product and/or process innovation. The third indicator measures the success of product innovation effort. Fourth, the number of new or improved products introduced in a three-year period controlled for the size of the business, in this case the number of products per 100 employees, is used to indicate the intensity of product innovation in the business.

MacPherson (1998), based on a survey of Scientific Instruments businesses in New York State in 1994, measures innovation performance as the proportion of a business's total sales in a specific year represented by products that had been introduced by those businesses over the previous five years.

Zucker, Darby and Armstrong (1998), in analysing geographically localised knowledge spillovers in the biotechnology industry in California, use the number of products that a business has in development at a specific time as a measure of the success of R&D effort. Based on a survey of state biotechnology businesses in 1994, they also use the number of products on the market at the same point in time and the growth in employment over a five-year period as proxy measures for the success of biotechnology businesses. This is based on the assumption that since the industry is characterised by radical technological change, growth in these factors implies successful innovation.

Freel (2000) identifies innovator businesses using a rate of innovation measure. This measure is based on the number of new products introduced as a proportion of a business's product base. New products in this case are defined as those that are "new to the company and represent a significant addition to the [product] portfolio" (2000:43).

To determine the appropriate measure of innovation for this study it is necessary to consider the appropriateness of using patent data in an Irish context. Irish businesses have lower incidences of patent applications than other European countries. The Enterprise Strategy Group show that in 2000 Ireland had less than half the number of patent applications to the European and US patent offices per million population than the average European Union level (2005:62). This may be due to the structure of the Irish economy which is characterised by a high dependence on foreign direct investment. Foreign multinationals with branches in Ireland may be expected to undertake R&D in their home countries and register patents there. For this reason, using patents may underestimate the extent of product innovation in Irish high-technology businesses. It has already been noted that patents, by their nature, exclude process innovation.

Flor and Oltra (2004) argue that primary survey data is a superior method of identifying the level of business-level innovation. Although they are concerned directly with the Spanish ceramic tile industry, their observations on the appropriateness of patents as a measure of innovation may also be relevant for other industries. They note that businesses may manufacture sub-components of a product or provide services to enable a final product be produced and while the manufacturer of the final product may be identified as an innovator in trade and technical journals the sub-component manufacturer or service provider may not be identified. These intermediate product and service providers would correctly be identified in surveys as innovators (Flor and Oltra, 2004:344)

This study uses original survey data to measure innovation output in Irish high-technology businesses. Such a survey identifies the incidence and intensity of both product and process innovation in these businesses.

The focus of attention now switches to the inputs to innovation. In particular, as set out in Section 2.6, this study is concerned with the relative importance for innovation of in-company research and development (R&D) and interaction with other businesses, academic-based researchers and innovation-supporting agencies. The following sections consider empirical studies on each of these inputs. Section 3.2 is concerned with in-company R&D activity. Section 3.3 considers interaction firstly with other businesses and secondly with non-business organisations, such as universities and innovation-supporting agencies. Section 3.4 is concerned with the spatial aspects of interaction and the extent to which geographical proximity affects the incidence, frequency and/or effectiveness of interaction for innovation.

3.2 Research and Development Inputs

Empirical studies have shown that there is a positive relationship between innovation and in-company R&D. This may not be surprising given that a central objective of R&D is the generation of new products and processes. However, there is evidence that the unit of analysis affects the strength of the relationship between the two variables.

Audretsch (1998) notes that the empirical relationship between knowledge inputs, such as R&D expenditure, and innovative outputs, such as patent registrations, is stronger at higher levels of aggregation. At national level there is a strong relationship between the level of expenditure on R&D and the extent of innovative activity, as measured by the number of patents registered. However, at the business level there is a weaker link between inputs and outputs since not all innovative activity leads to commercially viable products worthy of patents. Of course the output measure used may mean that process innovation, which by its nature does not lead to a patent registration, is not included.

Business level analysis also points to a positive relationship between R&D expenditure within the business and that business' innovation output. Based on survey data of Northern Irish businesses, Harris and Trainor (1995) find the "probability of patenting and innovation is significantly determined by the amount of resources formally committed to R&D" (1995:598).

Freel (2000) examined the relationship between research and development spending and innovative performance, using data from a survey of 228 manufacturing small and medium-sized enterprises (SMEs) in the West Midlands region of the UK. The study tests the hypothesis that R&D intensity is likely to be greater among innovator businesses, defined as those businesses that have at least 20% of the business's product base consisting of newly introduced products. The study finds that innovator businesses are likely to spend more, relative to size, on R&D.

Both Harris and Trainor (1995) and Freel (2000) estimate a direct positive relationship between R&D effort and innovative output. Cohen and Levinthal (1989 and 1990) test for an indirect relationship between R&D effort and innovative output.

Cohen and Levinthal (1990) suggest that businesses invest in R&D, not only to develop new products and processes, but also to create and sustain within the business what they term 'absorptive capacity'. This is the ability of the business to identify and exploit new technological opportunities from outside the business. The characteristics of knowledge within an industry, for example whether it is codified or tacit, that affect the level of difficulty in learning may be a determinant of investment in R&D. In this case, even when knowledge generated by R&D effort is only partially excludable businesses still invest in R&D as it enables them to identify and exploit potentially useful knowledge generated by research institutions or universities and competitor businesses.

Cohen and Levinthal (1990) estimate the effects on R&D intensity, measured as R&D expenditures as a percentage of sales, of technological opportunity and appropriability. Technological opportunity is measured using data from a survey of R&D managers in American manufacturing companies in 1983, who were asked to indicate the relevance of eleven basic and applied fields of science and the importance of external sources of knowledge to innovation in their businesses. The external sources of knowledge were equipment suppliers, materials suppliers, users of the industry's products, government laboratories and agencies and universities. Appropriability indicators are based on data from the same survey of R&D managers who were asked to indicate the effectiveness of mechanisms used by businesses to appropriate the benefits from innovation. These are patents to prevent imitation, patents to secure royalties, secrecy, lead time, learning curve effects and sales of complementary goods and services. Their results show that businesses' R&D intensity is positively affected by the degree to which learning in their industry is more difficult. This suggests that, as applied science fields are more complex than basic sciences, the technology which the company is developing affects the intensity of R&D. For high-technology businesses therefore, which is the focus of this thesis, it may be expected R&D is an important input for innovation.

However, the apparent inconsistency found by Audretsch's (1998) survey between the units of analysis raises the question of whether there is another source of knowledge for innovative businesses other than in-company R&D. Also, Cohen and Levinthal's (1990) finding that businesses invest in R&D to build absorptive capacity implies that there is technological knowledge that originates outside of the business but that can be utilised by the business. Recent literature has pointed to the importance of knowledge spillovers from other businesses, including suppliers, customers and competitors, and research institutions such as universities. The theoretical basis for interaction as a source of innovation is discussed in Section 2.4. There is a growing empirical literature on the role of interaction as a source of knowledge for innovation which is discussed in the next section. The following section considers evidence on the spatial aspect of interaction for innovation.

3.3 Innovation and Interaction

Recent empirical studies in the areas of regional science, organisational strategy and innovation have focused on the role played by interaction or networking on business-level innovation. The basis of this work is the concept of learning and knowledge creation as a social and interactive phenomenon, which is particularly important in relation to tacit knowledge transfer interaction. This section considers interaction between businesses and between businesses and other organisations.

3.3.1 Inter-business Interaction

Since the mid-1980s there has been mounting empirical evidence to suggest that interaction between businesses has a positive role on business-level innovation. Beesley and Rothwell (1987), Lawton-Smith (1991), Rothwell (1991) Hartman et al (1994), Roper (2001), Love and Roper (2001b), Freel (2003) indicate that interaction with other businesses increases the probability of innovation or the degree of innovation within a business. The latter three papers also consider the spatial aspect of this networking and are discussed in greater detail in Section 3.5, and this section presents some of the evidence in favour of interaction as a source of knowledge for innovation.

Jaffe (1986) finds that innovative output is greater in businesses that operate in industries which are characterised by higher levels of R&D. The model implies that a "spillover pool" is created among businesses using similar technologies performing R&D and that this spillover pool may benefit a particular business' innovative output directly and may also increase the productivity of that business' own R&D (1986:990). The results indicate that businesses whose R&D is in technological areas where there is a high level of R&D by other businesses have more patents per dollar of R&D spending. Jaffe views these results as "substantiating the spillover phenomenon" (1986:998). This finding is consistent with the frameworks considered in Section 2.4 in Chapter 2 which suggest interaction is an important source of knowledge for innovation.

Becker and Dietz (2004), based on a survey of German manufacturing businesses, find R&D co-operation positively affects the probability of a business introducing new products. They find that this R&D co-operation complements and improves in-house R&D activity. This is consistent with Jaffe (1986) finding that R&D spillovers positively affect a business' innovation output, though Jaffe's (1986) findings did not refer directly to formal R&D co-operation between businesses.

The question prompted by these studies is why businesses engage in external interaction, rather than rely on, say, in-company R&D. Oerlemans et al (2001) examine this question using data from a survey of 365 manufacturing and services businesses in the Netherlands. The study finds that interaction with other businesses, customers, suppliers and competitors, positively contributes to innovation output in a business. Furthermore Oerlemans et al (2001) contend that businesses engage in innovative networks only if there is a strong internal need to do, being the need to fill some internal gap in resources or ability to utilise resources. More radical innovation requires more localised ties, though the spatial aspects of interaction are discussed later in Section 3.4.

Appleyard (1996) explores the nature of inter-business interaction within a high-technology sector, the semi-conductor industry. She identifies the mechanisms by which technical knowledge is diffused among businesses in this industry. A survey of 96 U.S. and 27 Japanese businesses within the industry in 1994 and 1995 finds that public channels of communication play a central role in knowledge transfer. This implies that geographic proximity is less important in the transmission of technical knowledge. The public channels identified in the survey include patent documentation, reverse engineering of patented products, company newsletters, trade journals and the popular press. The use of personal contacts in businesses in the same industry is rated lowly in a list of sources of technical knowledge, suggesting that informal networking is not an important conduit of knowledge.

In this thesis both formal and informal, including unintentional, inter-business interaction for innovation is considered. This means that both tacit and explicit knowledge are explored as potential sources of innovation. The definition of interaction used for this thesis is set out in Section 4.4.

3.3.2 Non-Business/Academic Interaction

Other businesses are not the only potential organisations from which knowledge for innovation can spill over. For example, Porter and Stern identify "institutes for collaboration" (2001:30) that support innovation within business, and may include universities and publicly funded research centres. While they note that interaction with these institutes for collaboration is not automatic, their presence generates knowledge that is commercially exploitable by businesses. Porter (1998) also states that an important element of clusters is the presence of institutions such as universities, enterprise agencies and trade associations which promote innovation in the businesses within a cluster through research, education and technical support.

Mansfield (1995) finds that a substantial amount of innovation in high-technology industries has been based directly on academic research. The study is based on data on 66 businesses in 7 manufacturing industries and 200 academic researchers for the period 1975 to 1985. The study finds that 11% of new products and 9% of new processes in these industries would, at best, have been substantially delayed without recent academic research, which the study defines as academic research completed less than 15 years before the commercialisation of the innovation. For the pharmaceutical industry this figure is 27% for product innovation and 29% for process innovation.

Using bibliographic data on papers published between 1980 and 1994 Cockburn and Henderson (1998) find a strong and significantly positive correlation between the co-authorship of papers by private and public researchers and business-level innovation performance.

There is a sizeable and growing empirical literature on the extent of business and university linkages (For example, Hicks, Isard and Martin, 1996; Henderson, Jaffe and Trajtenberg, 1998; Schartinger, Schibany and Gassler, 2001; Agrawal and Henderson, 2002; Schartinger et al, 2002; Cohen, Nelson and Walsh, 2002; Monjon and Waelbroeck, 2003; Motohashi, 2005 and Veuglers and Cassiman, 2005). There are varying levels of interaction between businesses and universities reported in these studies, though all indicate that universities are a source of knowledge for business innovation. This thesis will also consider academic-based researchers as a potential source of knowledge for innovation in Irish high-technology businesses.

The important aspect for this thesis however is the relative importance of interaction with other businesses and with universities and innovation-supporting agencies for a business' level of innovation. The critical element is not necessarily the absolute level of interaction with each agent but the contribution that interaction with each agent makes to the innovation activity within a business. Sections 4.4.4 and 4.4.5 in the next Chapter set out how interaction is measured in this study and a series of estimations of the relative importance of interaction with each agent as a driver of innovation is reported in Tables 6.4 to 6.8.

3.4 Spatial Aspects of Interaction

Section 2.5 discussed the theoretical bases for expecting geographical proximity to facilitate greater levels of interaction. Localisation and urbanisation economies suggest that businesses may benefit from localised knowledge spillovers by being located within a concentration of economic activity (McCann, 2001:60; Parr, 2002). Moulaert and Sekia (2003) survey what they describe as the range of "Territorial Innovation Models" which include industrial districts, innovative mileux, localized production systems, new industrial spaces, innovation clusters, regional innovation systems and learning regions. These models are based on interaction in the creation of a favourable innovation environment and stress the importance of proximity to facilitate interaction between businesses and institutions within the regions.

3.4.1 Spatial Distribution of Innovation

There is evidence to suggest that innovation is geographically concentrated. Breschi (2000) undertakes a cross-sector analysis of innovative activity to test whether spatial patterns of innovation differ across sectors according to the features of the underlying technology. Each technology is categorised based on Nelson and Winters (1982) concept of technological regime and, using data from the European Patent Office for

France, Italy, Germany and the UK, the study finds large differences in spatial patterns of innovation across technological classes, but similarities across countries in the spatial patterns of innovation for each technological class. This suggests that some technological classes, such as many chemical and electronic industries, are characterised by a high level spatial concentration. Technological classes that would be characterised by a relatively simple and explicit knowledge base, such as clothing and agriculture, display a lesser tendency to concentrate spatially.

Todtling (1992) presents an analysis of R&D and innovation activities in several Austrian regions. Data analysis of two surveys of Austrian businesses across regions suggests that innovation is differentiated across space. In the Austrian case it is found that product innovations and R&D are concentrated in the larger agglomerations and urban areas. Process innovation is more evident in old industrial areas and rural areas.

3.4.2 Geographical Proximity and Inter-Business Interaction

In early studies in the 1990s there is support for geographically bounded knowledge spillovers and there is also evidence that geographic clustering improves the process of diffusion of technologies among businesses. Baranes and Tropeano contend that closer geographic proximity fostering knowledge spillovers is a stylised fact (2003:446). Jaffe et al (1993) analyse the degree to which patents granted to inventors in a region cite earlier patents granted to inventors in the same region and find evidence that knowledge spillovers tend to be spatially bounded. Audretsch and Feldman (1996) find a positive relationship between the level of R&D intensity and the importance of knowledge spillovers, based on a study of 4,200 manufacturing businesses that introduced commercial innovations in 1982 compiled by the US Small Business Administration. The spatial unit of observation is the U.S. state, which is "a crude proxy of the relevant economic market" (1996:631).

Baptista (2000) analysed the speed at which innovations diffuse within regions. Using data on two technologies, microprocessors and computer numerically controlled machine tools, there is evidence of a significant positive regional learning effect influencing diffusion. The speed with which businesses adopt a new technology is significantly positively affected by the number of previous adopters of that technology in the same region.

However, the there is less support in more recent studies that geographic proximity between businesses and between businesses and universities increases interaction and innovation. For instance, Love and Roper (2001), based on a survey of manufacturing plants in the UK, Ireland and Germany, find no evidence that businesses with more strongly developed regional or local external links or collaborative networks develop greater innovation intensity. Freel (2003) also finds little evidence from a survey of 597 businesses in Scotland and Northern England, that interaction for innovation is clustered geographically. There is evidence from this study though of an inverse relationship between the novelty of innovation and the distance over which interaction occurs. Businesses that introduce innovations that are new to the market, as opposed to simply new to the business, tend to interact over greater geographical distances (Freel, 2003:767).

This emerging conflict on the importance of geographical proximity for interaction for innovation warrants further analysis and this thesis estimates the effects on interaction of proximity in Section 7.

3.4.3 Proximity and University Interaction

Jaffe (1989) finds that coincidence in location between industry and university research has a positive impact on commercial innovation, as measured by the level of corporate patents. Acs, Audretsch and Feldman (1991) re-estimate Jaffe's (1989) model using a different measure of innovative activity though their results are consistent with Jaffe's findings. In fact, they find a greater impact of university spillovers on business innovation using their different measure of innovation output. There is also stronger evidence for the importance of proximity.

MacPherson (1998) finds that businesses located closer to academic resources tend to display higher levels of innovative activity. Using a database of 204 businesses in the Scientific Instruments industry in New York State, the analysis shows that knowledge spillovers from university-based researchers are geographically localised and that the intensity of interaction diminishes as time-distance increases. The intensity of interaction between businesses and universities, measured by the number of contacts over a four-year period, also has a negative relationship with time-distance. This means that businesses are less likely to maintain contact with university researchers that are more distant. There is a positive relationship between innovation performance and interaction intensity, though it is unclear from the study whether these interactions consist of formal, market-based transactions or informal meetings.

Audretsch and Stephan (1996) also seek to shed light on the nature of the relationship between high-technology businesses and academic researchers. Based on data from the prospectuses of biotechnology businesses that prepared Initial Public Offerings (IPOs) for stock market listing between March 1990 and November 1992 and controlling for both the density of biotechnology businesses and the role played by the scientist, they find that geographic proximity does not play an important role for most links. However, considering the role played by the scientist in the business, the study finds that where the scientist is involved as a founder of the business there is a greater probability that the business and scientist reside in the same region. They find that the "importance of proximity is shaped by the role played by the scientist" (1996:650).

The Audretsch and Stephan (1996) findings suggest that the existence of scientists or university faculties of itself is not a sufficient factor in the development of local links between businesses and those scientists. However, the study focuses on formal links between biotechnology businesses and scientists, through the IPO process. As part of that process listing businesses seek particular characteristics to support the listing process. Informal links with scientists in the same region as the business may still contribute to innovative activity, and Audretsch and Stephan (1996) suggest that future studies should look at how the role of geography varies by function and region, rather than at whether geography plays a role.

3.4.4 Measuring Proximity

Most studies, particularly in the US, use coincidence of location of businesses or universities in a particular region as a measure of proximity (for example, Jaffe, 1989; Jaffe et al, 1993; Audretsch and Feldman, 1996).

There are two difficulties with this measure for this thesis. First, there is the difficulty on deciding on an appropriate geographical area as the unit of analysis. Using a politically or geographically defined region implies that there is reason to expect that businesses that share that region may be more likely to interact than businesses from different regions. However, defined regions impose a structure that may not coincide with the market. Also, a particular business may more closely interact with another business located close to it, irrespective of one or other business's location in a different political or administrative region. Any business may be at the edge of a geographical or political region and so their interaction with businesses that are close to them in geographical terms is not captured or is classified as inter-regional interaction. Businesses at the edges of specified regions may be closer spatially, culturally or technologically to businesses at the edges of neighbouring regions. Second, the size of Ireland militates against finding a workable disaggregation, where travel distances are not as onerous as they would be in the U.S. for example.

An alternative to co-location as an indicator of geographic proximity is time-distance, used by MacPherson (1998). This represents the estimated one-way driving time involved in having a face-to-face meeting between the business representative and a university contact. This type of variable is possible using survey data. Sections 4.4.4 and 4.4.5 outline the approach adopted to measuring proximity in this thesis.

3.5 Irish Studies of Innovation and Technological Spillovers

This thesis is concerned with the innovative performance of Irish high-technology businesses. There are a small, but growing, number of Irish studies of innovation and the relative importance for business innovation of interaction and geographical proximity. The growth in the number of these studies reflects the importance of business innovation as the driver of economic growth post ‘Celtic Tiger’.

To date however, most of these studies focus on the role of spillovers, particularly from multinational businesses to local businesses, in generating productivity improvements in indigenous Irish businesses. These studies present evidence on the likelihood of such spillovers, rather than on the mechanisms by which these spillovers occur, for example whether these spillovers arise as a result of informal contact or are market mediated. These studies also tend not to consider spatial aspects in explaining the existence of spillovers.

McCartney and Teague (1997) study innovations in a specific aspect of a business, human resource management. Using survey data of private sector establishments in

Ireland of 50 or more employees in one of three industries, *Food, Drink and Tobacco*, *Electronics* and *Finance*, this analysis estimates the likelihood of an establishment adopting High Performance Workplace Organisation practices. The adoption of this new process of human resource management is regressed on four categories of independent variables. The first category is structural and environmental factors including establishment age and size and industrial sector. The second category comprised dummy variables representing the nationality of the parent business of the establishment. The third category comprised variables relating to the industrial relations practices within businesses, including variables estimating union strength and industrial relations history. The final category estimated the extent to which businesses adopt high value added strategies as opposed to low cost based competitive strategies. The study finds that businesses that are more internationally focused are more likely to adopt new processes. The authors also find that Irish exporters "are sensitive to and influenced by organisational reforms of international competitors….and multinationals operating in Ireland are diffusing advanced employment or human resource management systems in Ireland" (1997:396).

Further evidence of the effect of innovation in multinational companies on local businesses' innovative output is contained in Ruane and Ugur (2002). They look for evidence that foreign direct investment has had a positive effect on the productivity of Irish-owned businesses. Productivity in an Irish plant is considered to be a function of the capital intensity of that plant, the ratio of skilled to unskilled workers and the extent to which there are foreign owned plants in the same NACE sector. The model is estimated for 2, 3 and 4 digit NACE levels.

Based on business level panel data from Ireland’s Census of Industrial Production for 1991 to 1998 and using absolute levels of employment in the multinational sector as a measure of the extent of foreign presence in an industry, they find evidence that the spillover effect is both positive and significant. The study finds that the existence of foreign businesses within the same NACE industrial sector has a positive influence on Irish businesses' productivity. This is considered by the authors to occur through positive productivity spillovers from foreign multinational companies with plants in Ireland to indigenous businesses. The authors accept that, if these positive spillovers exist, there is a need to understand the process by which these spillovers occur, what the authors call the “conduits for such spillovers” (2002:14).

In another study of knowledge flows and spillovers between foreign multinational companies and local businesses, Hewitt-Dundas et al (2005) compare the process of knowledge transfer in the Republic and Northern Ireland. This study is based on data from a business-level survey of large multinational companies with plants in Ireland. Comparisons of activity in the Republic and Northern Ireland show that less sourcing and developmental interaction occurs in the North. There is a lag in the adoption of best practice techniques in local businesses, though that lag is more pronounced in Northern businesses. There is found to be greater potential for knowledge transfer in the Republic because the extent of local sourcing by multinational companies has increased since the 1980s.

Harris and Trainor (1995) identified and estimated the factors determining the likelihood of businesses in Northern Ireland to innovate. Based on survey data of Northern Irish businesses, they find that higher R&D spending leads to a higher probability of innovating. The authors use a production function approach and specify the relationship between innovation output and inputs as it. Harris and Trainor (1995) find that this R&D expenditure in turn is positively affected by higher profit margins based on data from the 1991 survey of manufacturing in Northern Ireland. R&D expenditure itself is considered to be a function of market structure, that is monopoly power of the business within the industry, and business size, as measured by the number of employees. This aspect is presented in more detail in Section 3.3. While recognising that the Northern Ireland economy of the time was not characterised by high levels of R&D inputs and innovation outputs, the study shows that externally-owned businesses are more likely to innovate, partly because of greater R&D expenditure and also because of inward technology transfer of which the writers find some evidence.

This thesis builds on the findings from these studies by exploring further the nature and extent of interactions between businesses in a specific industry, and broadens the scope to consider knowledge flows and interaction between local businesses and research institutions, as well as multinational companies. With the exception of Harris and Trainor (1995), who include in their analysis a dummy variable indicating the focal business's location in Belfast, the papers above are not concerned with spatial aspects of technological spillovers or the relative likelihood of spillovers among businesses in the same geographical area. Two Irish studies that consider the spatial dimension directly is Roper (2001).

Drawing on the urban-hierarchy model, Roper (2001) considers the impact of networking and location on a business's innovative activity. The paper identifies four types of area, urban, urban-periphery, second-centre and rural. The effect on innovative output of location within one of these areas is estimated. The effect on the likelihood of introducing new or improved products and processes of interaction between businesses within the same ownership group and between businesses unrelated by ownership is also estimated. Roper (2001) sheds light on the roles of interaction and location in the innovation process in Ireland, though it identifies whether businesses location in the urban-rural structure matters for innovation, and is not directly concerned with how geographic proximity works to influence innovative performance.

It can be seen that empirical work on the processes and determinants of innovation in Irish businesses is limited. To date most of this work has concentrated on finding evidence for knowledge spillovers, particularly from multinational companies to indigenous companies, and evidence of agglomeration economies.

3.6 Modelling and Estimating the Drivers of Innovation in Irish High-Technology Businesses

This Chapter has presented some of the varied and growing empirical literature on the drivers of innovation in business and the extent to which spatial factors influence levels of innovation. This thesis contributes to this literature. Statistical analysis of the survey of innovation in Irish high-technology businesses are reported in Chapters 5 to 7 of this thesis. In these Chapters the results are compared to the findings of the empirical studies reviewed earlier in this Chapter.

Chapter 4 sets out the fieldwork methodology used to gather appropriate survey data. The sample frame of Irish high-technology businesses is described in detail. The survey instrument design is discussed, setting out how each survey question is used to generate indicators of innovation outputs or inputs to the process of innovation, and the process adopted to administer the survey instrument is presented. Indicators of innovation inputs and outputs contained in the survey on which this thesis is based are based from The measures of innovation output and Survey response rates are reported by sector and nationality of ownership. The representativeness of the sample is tested and item and survey non-response are considered.

The results of the survey are reported in Chapter 5, where multivariate statistical analysis is used to identify patterns in innovation activity within sectors, indigenous and foreign-owned businesses and categories of business and age.

Econometric analysis, based on an innovation production function model, reported in Chapter 6 sheds light on the relative importance of the factors that drive innovation in Irish high-technology businesses. The use of an innovation production function in this thesis is based on similar approaches in Acs and Audretsch (1988), Geroski (1990), Harris and Trainor (1995), Audretsch and Feldman (1996), Oerlemans et al (2001), Roper (2001) and Freel (2003). Freel refers to this approach as “established practice of modelling innovation output” (2003:756). An innovation function approach implies that “innovation output depends on the presence and volume of innovation resources and the utilisation of these internal and external resources in the innovation process” (Oerlemans et al, 2001:9). Innovation production functions are estimated for a number of product and process innovation output indicators. The policy implications of this analysis are considered at the end of Chapter 6.

Using the same survey data, the spatial dispersion of interaction between high-technology businesses and other interaction agents is investigated in Chapter 7. The extent to which interaction occurs on a regional or local basis is explored, as well as the effect on innovation of agglomeration of economic activity in urban areas. Chapter 8 brings together the summary findings of the analyses presented in the previous three Chapters and discusses the implications for Irish industrial, enterprise, innovation and regional policies.

CHAPTER 4: FIELDWORK – CONDUCTING A SURVEY OF INNOVATION ACTIVITY IN IRISH 'HIGH-TECHNOLOGY' BUSINESSES

An original survey database is used in Chapters 5, 6 and 7 to examine the drivers of innovation in Ireland's 'high-technology' sectors and the extent to which interaction for innovation occurs locally or regionally. This Chapter presents the fieldwork undertaken to generate the survey database.

The Chapter is set out as follows. First, the rationale for selecting Ireland's 'high-technology' sectors for analysis is discussed and the sectors that are considered to be 'high-technology' are identified. Second the construction of a sample frame of 'high-technology' businesses is presented and its composition is analysed. Third the basis for using a self-administered postal/email questionnaire is explained and the design of the survey instrument is outlined. The survey questionnaire is discussed in detail. Fourth, the method used to administer the survey instrument is discussed. The final section considers the extent to which the survey results are representative of the population of the 'high-technology' businesses in Ireland. To do this, survey results for particular variables are compared to census data for the sectors as a whole. The sample frame is also tested for response bias and item response rates are presented.

4.1. Identifying Irish 'High-Technology' Sectors

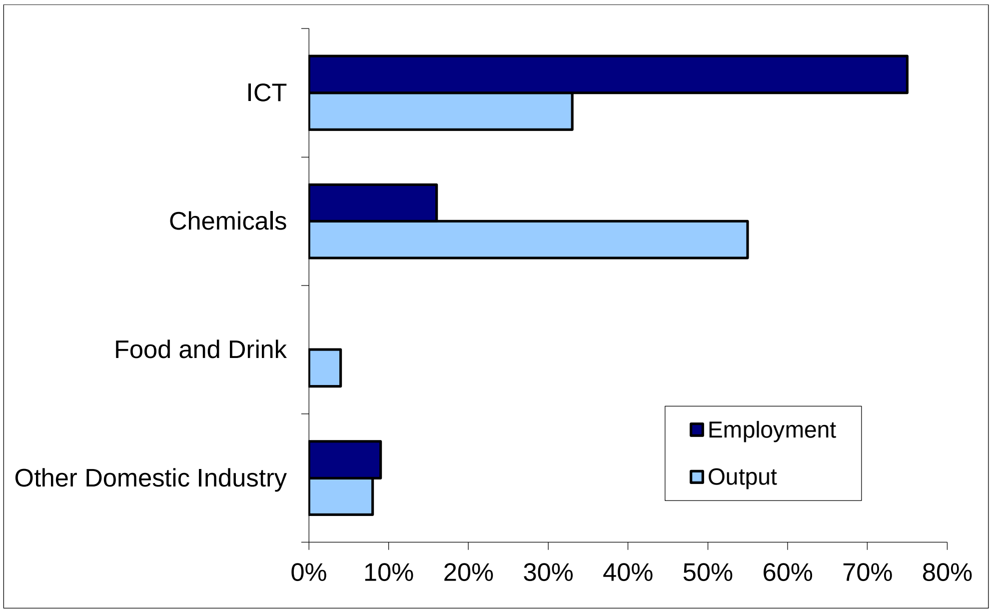
This section outlines the role played by businesses in 'high-technology' sectors in Ireland's recent economic growth and the importance of these sectors for policy makers for future Irish growth. Then, based on an OECD classification of industries by their levels of technology, Irish 'high-technology' sectors are identified.

This study's focus on 'high-technology' sectors is based on the significant contribution they have made to Ireland's recent economic growth (Department of Trade, Enterprise and Employment, 2003) and their anticipated importance to future growth (Enterprise Strategy Group, 2004).

4.1.1 'High-technology' Sectors and Ireland's Recent Growth Performance

The OECD contends that "in Ireland, high- and medium-technology manufacturing has been a driving force behind the recent economic expansion" (2001). This is supported by evidence of the share of Irish growth that is accounted for by the *ICT* and *Chemicals* (including *Pharmaceuticals*) sectors, which are typical high-technology manufacturing sectors since the mid-1990s. Figure 4.1 shows the contribution to both total industrial output and employment growth of these sectors in the second half of the 1990s. Between them these sectors account for approximately 90% of the growth in industrial output and employment over the period (Department of Enterprise, Trade and Employment, 2003:67).

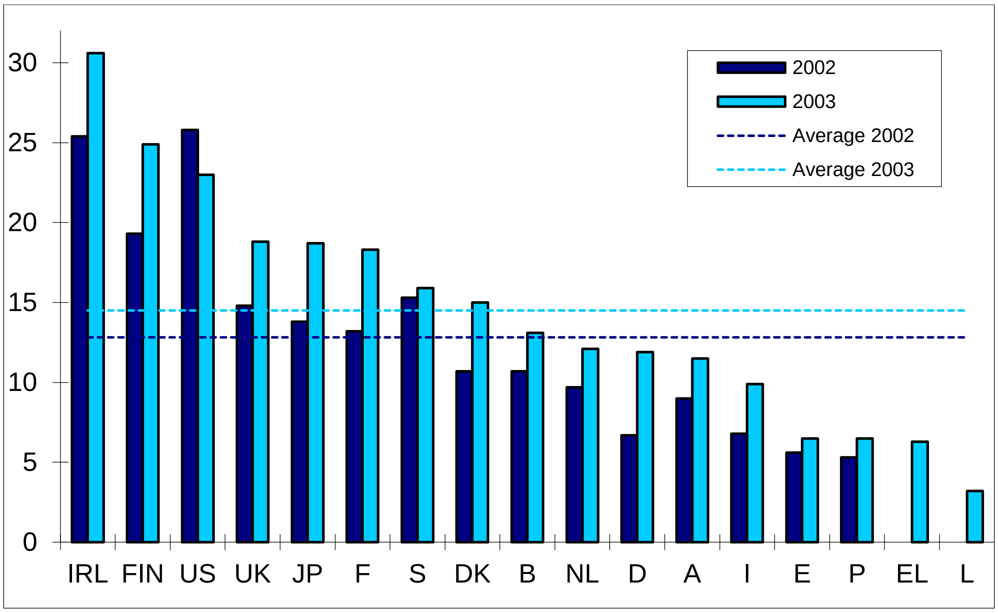
Figure 4.1: Contribution of Selected Sectors to Output and Employment Growth in Ireland 1995 to 2000



Source: Department of Enterprise, Trade and Employment (2003:68)

Figure 4.2 shows the contribution of 'high-technology' manufacturing sectors to the Irish economy in 2002 and 2003, after the 'Celtic Tiger' period of the 1990s. The share of value added by high-technology sectors in Ireland is approximately double the OECD average in both years (European Commission, 2003a). In 2002 high-technology sectors accounted for 25.4% of manufacturing value-added compared to an OECD average of 12.8%. In 2003 the high-technology sectors' share increased to 30.6% and the OECD average rose to 14.5%. This suggests that 'high-technology' sectors remain key components of industrial output.

Figure 4.2: High-Technology Sectors Share of Manufacturing Value-Added 2002 and 2003



Source: European Commission (2003a)

In Figure 4.2, high-technology sectors are defined by the European Commission using an OECD classification of sectors into high, medium and low technology categories. These categories are set out in Table 4.1. Also presented are the NACE Rev 1.1 codes for the activities in each category. NACE is the standard industrial classification in the European Union and is administered by Eurostat. Businesses may be classified by activity into broad (two-digit) levels or in more narrow (three- and four-digit) levels.

This division of manufacturing industries is determined after ranking the industries according to their average aggregate R&D intensities between 1991 and 1997. R&D intensity is based on three indicators; R&D expenditures divided by value added, R&D expenditures divided by gross output and R&D expenditures plus technology embodied in intermediate and investment goods divided by gross output (OECD, 2001).

Table 4.1 – OECD Classification of High, Medium and Low Technology Sectors	
<u>High-Technology Manufacturing Industries</u>	<u>NACE rev.1</u>
Manufacture of pharmaceuticals, medicinal chemicals and botanical products	244
Manufacture of office machinery and computers	30
Manufacture of radio, television and communication equipment and apparatus	32
Manufacture of medical, precision and optical instruments, watches and clocks	33
Manufacture of aircraft and spacecraft	353
<u>Medium-High-Technology Manufacturing Industries</u>	<u>NACE rev.1</u>
Manufacture of chemicals and chemical products (excl pharmaceuticals, medicinal chemicals and botanical products)	24 (excl 244)
Manufacture of machinery and equipment n.e.c.	29
Manufacture of electrical machinery and apparatus n.e.c.	31
Manufacture of motor vehicles, trailers and semi-trailers	34
Manufacture of railway and tramway locomotives and rolling stock	352
Manufacture of motorcycles and bicycles	354
Manufacture of other transport equipment n.e.c.	355
<u>Medium-Low-Technology Manufacturing Industries</u>	<u>NACE rev.1</u>
Manufacture of coke, refined petroleum and nuclear fuel	23
Manufacture of rubber and plastic products	25
Manufacture of other non-metallic mineral products	26
Manufacture of basic metals	27
Manufacture of fabricated metal products, except machinery and equipment	28
Building and repairing of ships and boats	351
<u>Low-Technology Manufacturing Industries</u>	<u>NACE rev.1</u>
Manufacture of food products and beverages	15
Manufacture of tobacco products	16
Manufacture of textiles	17
Manufacture of wearing apparel; dressing and dyeing of fur	18
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	19
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	20
Manufacture of pulp, paper and paper products	21
Publishing, printing and reproduction of recorded media	22
Manufacture of furniture; manufacturing n.e.c.	36
Recycling	37

Source: European Commission, 2003b

This categorization is important in policy setting terms as it is used in the construction of the European Commission Innovation Scoreboard to monitor EU countries' performance against the objectives set out in the Lisbon Agenda (European Commission, 2003b).

4.1.2 The Importance of 'High-technology' Sectors for Future Irish Growth

A consistent theme for Irish policy-makers in recent years has been the crucial role of innovation in Irish 'high-technology' businesses as a source of future growth and competitiveness. The National Competitiveness Council states that a science and technology base in Ireland is essential to provide a basis for future growth in Ireland (2001:26). In a later report Forfás maintain that productivity growth, based on innovation and technology, must increasingly become the driver of Irish economic growth (2003:27). The Enterprise Strategy Group (ESG) identified expertise in technology and product and process development as being among the critical sources of competitive advantage for the Irish economy in the future (2004:xiv).

The ESG identified key sectors that "will play a significant role in Ireland's economy over the next decade" (2004:69). These sectors included six "high-value" manufacturing sectors (*Pharmaceuticals/ Biotechnology*, *Food*, *ICT*, *Medical Technologies*, *Engineering* and *Consumer Goods*) and internationally-traded services (2004:70). It is clear that Irish policy makers view these sectors as delivering the required productivity improvements to underpin future Irish competitiveness.

4.1.3 Identifying Irish 'High-technology' Sectors

Table 4.1, presented earlier, sets out the OECD classification of high-technology, medium to high-technology, medium to low-technology and low-technology sectors.

Of the six "high-value" manufacturing sectors identified by the ESG, *Food* and *Consumer Goods* (which includes clothing, textiles, sporting goods eyewear, jewellery, toys, games and cosmetics) are not 'high- or medium-high technology' sectors based on the classification set out in Table 4.1. This study therefore focuses on the remaining four sectors identified by the ESG; *Pharmaceuticals/Biotechnology*, *ICT*, *Medical Technologies* and *Engineering*.

This study does not consider directly the innovative activity in the internationally traded services sector identified in the ESG report. The services included in this category are very diverse, including education services, financial services, healthcare services, tourism and agricultural and bloodstock services. Businesses in each of the high-technology sectors selected for analysis share underlying technologies and/or operate in similar markets. This is not the case with a categorisation of businesses as broad as internationally traded services. There are businesses included in the survey sample that offer both products and services to the market. In fact the definition of product innovation used in this study includes the introduction of new services to the market.

The next section sets out how a useful directory of businesses in Irish high-technology sectors is generated.

4.2. Generating a Sample Frame

There is no single directory of businesses in the relevant high-technology sectors. The survey sample is drawn from two databases of businesses maintained by Irish industrial development agencies, Enterprise Ireland and IDA Ireland. First is the Source Ireland website, administered by Enterprise Ireland. This provides details of businesses registered with Enterprise Ireland, categorised by sector. These businesses are predominantly indigenous. The second source is the business directory published on the IDA Ireland website. The IDA Ireland business directory is composed of foreign-owned companies operations in Ireland that have received financial support from IDA Ireland to establish operations in Ireland. Table 4.2 presents the sectoral classification of the IDA Ireland and Enterprise Ireland business directories.

These business directories were chosen over alternatives, such as Kompass or telephone directories, because of the coverage of the IDA Ireland directory and the level of detail about each business available in the Enterprise Ireland directory, and these directories are freely available. The IDA Ireland directory is likely to include all foreign multinationals established in Ireland since these are likely to have sought and/or received grant or other assistance from IDA Ireland. The Enterprise Ireland directory provided contact names and telephone numbers for each business, which facilitated easier administration of the survey instrument. It can be expected that the businesses in these directories are supported by enterprise agencies and therefore the results of this thesis and its contribution to the policy debate would be germane.

The sectors from which the survey population is drawn are shown in italics in Table 4.2. The sectors chosen are those that most closely match the high-technology sectors identified in Table 4.1.

Three sectors have been selected from the Enterprise Ireland database, which closely match the OECD classification of high and medium-high technology sectors:

- *Chemicals and Pharmaceuticals*;
- *Computers, Software and Consulting*;
- *Electronic and Electrical Equipment*

and five sectors from the IDA Ireland database:

- *Pharmaceuticals*;
- *Chemicals*;
- *Information and Communications Technology* (ICT);
- *Medical Technology*;
- *Engineering*.

The number of businesses in each sector is set out in Section 4.4, later in this Chapter, when the construction of the survey sample and its representativeness of the population are presented.

Table 4.2 – Sectoral Classification of Irish Development Agencies Databases	
Enterprise Ireland (SourceIreland)	IDA Ireland
Chemicals and Pharmaceuticals	***Pharmaceuticals***
Clothing, Textiles and Footwear	***Information and Communication Technology (ICT)***
Computers, Software and Consulting	***Medical Technology***
Electronic and Electrical Equipment	International Financial Services
Food and Beverages	***Engineering***
International Services	International Services
Jewellery and Giftware	Consumer Products
Metal Products: Industrial and Household	***Chemicals***
Paper, Printing and Publishing	
Plant, Equipment and Construction	
Plastic and Rubber Products	
Timber and Furniture	
Transport and Power Equipment	

Source: www.idaireland.com; www.enterprise-ireland.com/sourceirelandsearch

These eight sectors may be grouped into three major sectors based on the similarity in the underlying technologies of each sector. A secondary benefit to this aggregation is the generation of sectors with sufficient observations for meaningful analysis and cross-sectoral comparison. The major sectors, and their component primary sectors, are set out in Table 4.3.

Each major sector brings together primary sectors that are similar in terms of the technologies on which each is based. The *Medical Devices* sector is the only primary sector that may be classified in more than one major sector. Many medical devices are used in conjunction with pharmaceuticals, and so may rely on similar medical knowledge as the *Pharmaceutical* sector.

Table 4.3 – Major Sectors and Components	
Major Sectors	**Primary Sectors**
Chemicals and Pharmaceuticals	• Pharmaceuticals (IDA Database) • Chemicals (IDA Database) • Chemicals and Pharmaceuticals (EI Database)
ICT	• ICT (IDA Database) • Computers, Software and Consultancy (EI Database)
Electronic Devices and Engineering	• Medical Devices (IDA Database) • Engineering (IDA Database) • Electronic and Electrical Equipment (EI Database)

Source: www.idaireland.com; www.enterprise-ireland.com/sourceirelandsearch

For this study, the *Medical Devices* sector is included with *Electronic and Electrical Equipment* and *Engineering* sectors. Eucomed is the European representative body for the Medical Devices industry. It maintains that a fundamental difference between the Medical Devices industry and the Pharmaceutical industry is that Medical Devices are based on mechanical, electrical and materials engineering, while Pharmaceuticals is based on pharmacology and chemistry (Eucomed, 2004). The Economist magazine contends that “the device industry is more like Silicon Valley than New Jersey, where America’s pharmaceutical giants are clustered” (2000:62).

In order to confirm this view of the *Medical Devices* sector a meeting was held with Ms. Sharon Higgins, Director of the Irish Medical Devices Association (IMDA), the industry’s representative body in Ireland, on February 11, 2004. She stressed the importance of electronics and engineering disciplines to technology used in the

Medical Devices sector both nationally and globally. It was noted that, notwithstanding new trends to complement devices with drug treatments, the technological base of the sector in Ireland remains engineering with a medical application. For these reasons, the *Medical Devices* sector is included in the *Electronic Devices and Engineering* sector, rather than the pharmaceutical sector.

4.2.1 Constructing the Survey Sample

The first step in constructing a useful survey sample database is to analyse the Enterprise Ireland and IDA Ireland databases of businesses. Table 4.4 presents a breakdown of the number of businesses contained on each of these databases and the number of businesses that are surveyed.

Table 4.4 – Survey Sample by Sector (number of businesses)

	Total Businesses on Database	Total Businesses Surveyed	%
IDA Ireland Database			
Pharmaceuticals	81	68	84%
Chemical	22	18	82%
Engineering	128	103	84%
Medical Technologies	67	53	80%
ICT	199	129	65%
Sub-Total	*497*	*371*	*75%*
Enterprise Ireland Database			
Computers, Software and Consultancy	329	222	67%
Chemicals and Pharmaceuticals	202	97	48%
Electronic and Electrical Equipment	189	167	88%
Sub-Total	*720*	*486*	*68%*
Total	*1,217*	*857*	*70%*

Source: www.idaireland.com; www.enterprise-ireland.com/sourceirelandsearch

The following are the reasons for the difference between the number of businesses surveyed and the number of businesses on the databases. SourceIreland, administered by Enterprise Ireland, is a list of companies used by businesses looking for suppliers in a range of sectors. Indigenous Irish businesses may register on this list as a form of marketing to potential customers. It is possible for businesses to register in more than one sector. Indeed, an incentive to do so may exist, as it may increase the likelihood that a potential customer sees the business' entry on the register. For the purposes of this survey it is necessary to avoid double-counting. Businesses are only included in one sector. Each is assigned to that sector representing the largest component of their business, based on information on their websites and the Kompass Directory (2004).

Another consideration is the appropriateness of the classification of some businesses within each sector. For example, several companies registered in the *Chemicals and Pharmaceuticals* sector on the Enterprise Ireland database identified their main business as the manufacture of headstones, pottery or concrete products. While companies may provide products and/or services to businesses in a 'high-technology' sector such as the *Chemicals* sector, they themselves would not be considered 'high-technology' according to the OECD classification set out earlier in Table 4.1. This is a particular problem in the *Chemical and Pharmaceutical* sector on the Enterprise Ireland register. Those businesses that are considered to be inappropriately classified are excluded from the survey sample. Table 4.4 shows that this resulted in 97 (48%) businesses on the SourceIreland database being surveyed.

The IDA Ireland database is also analysed to exclude businesses that had announced plans to open operations in Ireland but had not started at the time of the survey. Also, businesses that had been established since the end 2003 are excluded, as this is outside the study's reference period. Another issue which arose with many businesses listed on the IDA Ireland database, particularly in the *ICT* sector, is the existence of separate legal entities located at the same addresses and with the same managers. These difficulties arose most frequently in the *ICT* and *Computers, Software and Consultancy* sectors, in which approximately one third of businesses are not included in the survey sample.

After this analysis, 878 businesses were identified. Of these, 21 businesses are used to pilot test the survey instrument, resulting in a final survey population of 857 businesses. The representativeness of the survey population is discussed in Section 4.5.3.

4.3 Designing a Survey Instrument

The survey method adopted is a self-administered questionnaire, circulated by post or email. Personal interviews, face-to-face or by telephone, are considered as alternatives to a self-administered questionnaire. Postal/email questionnaires can be administered at a lower cost and in a shorter time-frame than personal interviews. It is most appropriate for larger sample sizes and where the sample is dispersed over a large area. The disadvantages of this approach are that survey and item non-response rates tend to be higher for self-administered questionnaires than interviews and more (complex) questions may be asked in interviews. However, this latter benefit is tempered by the prospect of introducing interviewer bias in explaining questions.

The size and dispersion of the sample frame mitigated against personal interviews. However, to encourage as high a response rate as possible, each potential respondent was contacted by telephone to introduce the study. This process is presented in more detail in Section 4.5.

The questionnaire was designed over a three month period, using input from two independent referees, one representing a small indigenous Irish software business and one from a multinational electronics business. The businesses with which these referees are associated are not included in the survey sample. The feedback related to the structure and length of the survey instrument and the clarity and wording of questions. As a result of this feedback, the initial questionnaire, which had 50 questions, was shortened considerably and was amended to include more interval measures. This was done for a number of reasons, all of which are expected to increase the response rate. First, the sensitivity of certain questions, such as those related to business profitability, was reduced. Second, the time required to complete the questionnaire was reduced. Third, the need for respondents to spend time seeking out information was removed, as this would result in reduced response.

Two significant examples of the changes in the initial questionnaire arising from this feedback are set out below.

Example 1: Level of Process Innovation

The aim of this question is to define process innovation for respondents and to identify, in detail, the types of process innovation carried out by the business. The definition and categories of process innovation are based on Schumpeter's definition of technological change (1934:66). Examples of the range of activities that may be included in each category of process innovation are included to help respondents contextualize the definition of process innovation in their business. The question asked respondents to indicate the success of process innovation, by estimating the contribution to profitability of each type of process innovation. This question is phrased as a contribution to profitability, since, unlike product innovation which is intended to generate turnover, process innovation may result in reduced costs as well as increased sales. This aspect of the question is intended to provide a measure of the success of process innovation in a similar way to the question on the success on product innovation. The original wording is set out below.

The aim of **process innovation** is to achieve improved efficiencies, lower costs and/or higher profitability. It may include

- the introduction of a method of production of an existing good or delivery of an existing service that is new to the business.
  (This may range from reorganising factory layout to switching from manual to automated processes in production)
- the reorganisation of management structures, support activities and/or methods of distribution for existing goods and services
  (This may range from altering functional reporting lines to the implementation of new computer systems, such as Enterprise Resource Planning Systems)
- entering a new market with an existing product or service,
  (This may range from repositioning existing products within a market to launching products already sold in the domestic market on a foreign market)
- the development of a new source of supply of materials or other inputs
  (This may range from introducing new equipment to the production process to outsourcing elements of the business.)

B.5. Please indicate the number of new processes introduced to your business in the three years to the end of 2003 and the *approximate* percentage contribution to net profit in 2003 made by these processes. *(If your business has not introduced a process please answer '0')*

	Number of Processes	**Contribution to Profit**
Introducing a new method of production or delivery of service		%
Reorganisation of management, support activities and/or methods of distribution		%
Developing a new source of supply		%
Entering a new market		%
Other *(please specify)* ________________		%

The referees suggested that the question would be difficult for respondents to answer, and as a result they may not continue with the remainder of the questionnaire. It was pointed out that, since many businesses are engaged in constant process improvements, it is almost impossible to estimate the contribution to profitability of any one single process innovation. It was also suggested that respondents would not easily be able to assign some process innovations to one category, as some may overlap across categories.

The question was redesigned and the corresponding question in the final survey questionnaire is set out below.

Process innovation is introduced to achieve improved efficiency, lower costs and/or higher profitability. It may include

(i) the introduction of a new method of production of existing goods or method of delivery of existing services,
(ii) the re-organisation of support activities, management structures or distribution channels,
(iii) the introduction of existing goods and/or services to new markets and
(iv) the introduction of a new source of supply of materials or other inputs.

B.3. Please indicate the extent to which your business introduced new processes between 2001 and 2003. *(Please tick one box)*

Continuously	**Frequently**	**Regularly**	**Rarely**	**Never**
☐	☐	☐	☐	☐

The question again defines process innovation, but examples are omitted as these may limit the respondent's view of what may be considered a process innovation. Respondents are asked to indicate the frequency of process innovation based on five categories from never to continuously. This was based on comments from both referees that they would expect continuous process innovations in their businesses if they are to be highly innovative and that they would measure the degree of process innovation by the frequency with which processes are introduced.

Example 2: Interaction with Agents

A feature of this study is analysis of interaction with group companies, suppliers, customers, competitors, academic-based researchers and innovation-supporting agencies. These six categories are referred to as interaction agents.

To shed light on interaction with these interaction agents, respondents are asked to indicate the incidence and frequency of interaction for product and process innovation between the respondent's business and each interaction agent. The first two questions require a yes/no answer to whether the business interacted with a particular interaction agent for product innovation and process innovation respectively. Examples of interaction are provided in each question. If interaction occurred, respondents are asked to briefly elaborate on the nature of these interactions. To facilitate measurement of proximity to each interaction agent, respondents are asked to indicate the location of the three most important agents in each category.

An identical set of questions is included for each interaction agent. The particular example presented here refers to interaction with customers.

C.16. Does your business interact with customers in relation to ***product innovation*** in your business?
(For example, business lunches at which new product ideas are discussed informally or formal presentations of new technology to customers or potential customers to elicit suggestions for potential commercial applications)

Yes ☐ No ☐

C.17. Does your business interact with customers in relation to ***process innovation*** in your business?
(For example, attending conferences or informal discussions on new production techniques or best practice or working with customers on the introduction of recognised quality standards such as ISO 9000)

Yes ☐ No ☐

If you answered no to questions C.16. and C.17, please skip to question C.22.

C.18. Please briefly elaborate on the nature of the interactions between your business and its customers in relation to new ***product*** development in your business.

____

____

C.19. Please briefly elaborate on the nature of the interactions between your business and its customers in relation to new ***process*** development in your business.

____

____

C.20. Please indicate the location (city or town) of the three most important customers with which your business interacts in relation to product innovation.

1. ______________________________________
2. ______________________________________
3. ______________________________________

C.21. Please indicate the location (city or town) of the three most important customers with which your business interacts in relation to process innovation.

1. ______________________________________
2. ______________________________________
3. ______________________________________

The referees suggested questions that required elaborate or written answers would not be answered by most respondents. Given the large number of survey requests received by businesses, the preference is for shorter questionnaires with more ‘tick-box’ type answers. Also, businesses may not be willing to identify the specific location of interaction agents as this may make it possible to identify those agents, which could be sensitive information. Questions, C.8 and C.9, in the final questionnaire, which relate to all interaction agents, are set out below.

C.8. Please indicate the frequency with which you have interacted with the following (whether formally or informally) in relation to product innovation in your business between 2001 and 2003. (If your business did not interact with any of the following in relation to product innovation, please tick 'Never')

	Continuous	**Frequent (Several times a year)**	**Regular (At least once a year)**	**Rare (Less than once a year)**	**Never**
Parent and subsidiary companies	☐	☐	☐	☐	☐
Suppliers of Equipment, Materials and/or Services	☐	☐	☐	☐	☐
Customers	☐	☐	☐	☐	☐
Competitors	☐	☐	☐	☐	☐
Academic-Based Researchers	☐	☐	☐	☐	☐
Innovation-Supporting Agencies	☐	☐	☐	☐	☐

C.9. For each category below, please determine the most important source of knowledge for your business' **product innovation** and estimate the average driving time (one-way) from your business. *(Where the relevant source of knowledge for any category is based outside of Ireland please answer '> 4 Hours')*

	N/A	**< ½ Hour**	**½ to 1 Hour**	**1 to 2 Hours**	**2 to 4 Hours**	**>4 Hours**
Parent or subsidiary company	☐	☐	☐	☐	☐	☐
Supplier of Equipment, Materials and/or Services	☐	☐	☐	☐	☐	☐
Customer	☐	☐	☐	☐	☐	☐
Competitor	☐	☐	☐	☐	☐	☐
Academic-Based Researcher	☐	☐	☐	☐	☐	☐
Innovation-Supporting Agency	☐	☐	☐	☐	☐	☐

These questions are designed to facilitate a more speedy response. Instead of asking, in separate questions, whether a respondent's business had interacted with each of the interaction agents, the question is designed to measure the frequency of interaction and if no interaction occurred the respondent would answer 'Never'. In this way two questions, one on the incidence of interaction and one on the frequency of interaction, are amalgamated.

Instead of identifying the location of the three most important interaction agents, respondents are asked to indicate the average one-way driving time to the single most important source of knowledge in each interaction agent category. The effect of this is to shorten the time required to complete the questionnaire. However, this meant that only the distance between the respondent's business and one interaction agent, albeit the most important, in each category can be measured. This means it is not possible to distinguish those businesses that interact with several agents, some local and others more distant. To facilitate such a distinction would require more questions on proximity on the questionnaire, lengthening it substantially and having a possible adverse effect on response rates. It was decided therefore, in the interest of achieving a higher response rate, to ask respondents to indicate proximity to the most important interaction agent.

Geographic proximity is measured using average one-way driving time from the business to the interaction agent. This measure is discussed in greater detail in Section 4.4.4 and is based on referees' comments that in business time taken to travel is a greater consideration for interaction than physical distance. However, using a standard travel time approach would make it difficult to distinguish between forms of travel while ensuring the question is short and clear.

The choice of interaction agent categories, the measurement of proximity (average one-way driving time) and the intervals into which driving time is divided are discussed in detail in Section 4.5 later in this Chapter, when the survey instrument is presented in detail.

The feedback element of the survey design provided a useful business perspective on the questionnaire, increasing its effectiveness and ultimately improving the response rate.

4.4 The Survey Instrument

The survey questionnaire is included in Appendix 1, which also contains the cover letter sent to each potential respondent. The survey contains 25 questions (some with sub-parts), divided into four sections. Section A, which contains 8 questions, focuses on Characteristics of the Business. Section B, with 3 questions, asks about Innovation in the Business. Section C is the longest section, with 11 questions, and relates to Sources of Innovation. Finally, Section D, with 3 questions, asks about the business' Competitive Environment. With the exception of one response, respondents to the questionnaire are not anonymous; contact details are provided, so that exact location is known and follow-up clarification questions are possible.

4.4.1 Characteristics of the Business

The first section contains questions in relation to the characteristics of the respondent business.

Question A.1 asked respondents whether their business is a member of a group of companies or a stand-alone business. If applicable, respondents are asked to identify, in Question A.2, the country in which the group headquarters is located. The electronic version of the questionnaire provided a list of countries from which the respondents selected the appropriate answer. This list is drawn from the range of countries identified as group headquarters on the IDA Ireland list of companies. These two questions make it possible to identify indigenous and foreign-owned businesses facilitating comparison between Irish and foreign-owned businesses in innovation activity, research and development effort and patterns of interaction. Hewitt-Dundas et al find “Irish plants of multinational companies…..represent a potentially important infusion of external knowledge into the Irish econom[y]” (2005:39).

In Questions A.3 to A.6 respondents are asked a series of questions relating to the nature of their business. Question A.3 asked respondents to indicate the year in which their businesses began operations in Ireland. From this information the age of the company’s Irish operations at the start of the reference period can be calculated. The question is phrased to make it easier for respondents, saving them time in calculating the company’s age. There is empirical evidence that the age of a business may affect innovation output (Galende and de la Fuente, 2003; Gordon and McCann, 2005). It is also worthwhile to test if the age of a business has different effects on product and process innovation. The implication is that younger businesses may tend to operate with newer technologies and offer new products to the market, while older businesses maybe more likely to engage in productivity improvements through process innovation.

Businesses are asked in Question A.4 to indicate the number of products and/or services their business provided to the market at the end of 2003. To reduce scope for misinterpretation in relation to the definition of products and services, the question included an example. It states “for example, if your business offers two types of pens and three types of paper, then the total number of products is five”. The results from this question are used to derive a measure of the intensity of innovation. This intensity measure is used to control for the effects of size or product range on innovation output, by enabling comparison across businesses of the scale of product innovation. Two businesses that introduce the same number of new products and services over a given period may not be equally innovative. For example the introduction of one new product or service may represent a doubling of the product range of one business and only a marginal increase in the product range of the other.

Respondents are asked in Question A.5 to estimate the number of employees in their business at the start and at the end of the reference period. Respondents are asked to estimate employee numbers in terms of full-time equivalent (FTE), and are told that, for example, two half-time employees is equivalent to one full-time employee. The number of employees is a standard measure of the size of a business (McPherson, 1998; Roper, 2001; Freel, 2001; Bougrain and Haudeville, 2002).

Question A.6 asked respondents to estimate the percentage of the business' workforce that possess a third-level degree or similar technical qualification as their highest qualification. Where employees possess higher educational qualifications they may be better able to perceive and employ new knowledge that exists outside the business with for example, suppliers, customers, academic-researchers or even other group companies (Cohen and Levinthal, 1989 and 1990; Forfás, 2005).

Respondents are asked about their business' performance from 2001 to 2003 in terms of profitability and growth in turnover. They are asked to indicate net profit as a percentage of turnover in 2003 in Question A.7 and the rate of growth in turnover over the three years to 2003 in Question A.8. These are used as indicators of the performance of the business over the three-year reference period. Business profitability is a very sensitive issue and it was confirmed by comments from referees at the pre-testing phase that many businesses are reluctant to divulge their absolute level of profit or net profit margin. The approach adopted here is to ask survey businesses to indicate their net profit margin within interval ranges. An option of 'Not in Profit' is provided and five intervals from 0% to 50%. A trade-off exists between the width of the intervals and the likelihood of response. This is borne out in the response rate to this question, which is answered by 167 (91%) respondents. Item response rates is discussed in detail in Section 4.7 later in this Chapter. Question A.8 asks respondents to indicate the rate of growth in sales in the three years between 2001 and 2003. Again, interval ranges are used, with ten intervals from 0% to 100% and two further options, a decline in sales and an increase greater than 100%.

4.4.2 Innovation Output Indicators

The second section of the questionnaire related to the respondent's innovation performance in the three years to the end of 2003. The questionnaire addresses both product and process innovation.

Product Innovation

Product innovation is defined on the questionnaire as the introduction to the market of a new product or service or the introduction to the market of an improved version of an existing product or service, which may include additional features or improved functionality. Question B.1 asked respondents how many new products and/or services their business introduced to the market between 2001 and 2003. The introduction of any new products and/or services means that the participant business is characterised as a product innovator. This question provides three measures of product innovation. The first is the incidence of product innovation, which is a binary variable taking a value of 1 if the business introduced any new products or services. The second measure is the absolute number of new products or services introduced over the reference period. The third measure uses responses to Question A.4 and Question B.1 to construct a measure of innovation intensity, by expressing the number of new products or services as a proportion of existing products. Also, Roper (2001) adopts the number of new products or services per 100 employees as a measure of product innovation intensity. Such a measure can be generated for this study using this Question B.1.

Respondents are also asked, in Question B.2, to estimate the percentage of business turnover in the three years to the end of 2003 generated by the newly introduced products and/or services. This is a measure of the success of product innovation and is similar to measures used in Roper (2001) and Love and Roper (2001).

Process Innovation

The survey questionnaire states the aim of process innovation to be improved efficiency, lower costs and/or higher profitability and suggests a number of examples of process innovation. These include the introduction of a new method of producing existing products or a new method of delivering existing services, the re-organisation of support activities, management structures or distribution channels, the introduction of existing products and/or services to new markets and the introduction of new sources of supply of materials or other inputs. Respondents are asked to indicate the extent to which their business introduced new processes between 2001 and 2003.

The response indicates firstly whether the business is a process innovator or not. If the business has not introduced any processes in that period it is not a process innovator.

Second, the question measures the frequency with which the business engages in process innovation. The question asks respondents to indicate the extent to which their business introduced new processes between 2001 and 2003 on a scale comprising never, rarely, regularly, frequently or continuously. As noted previously, the use of a frequency scale is based on comments from industry referees that they would measure the degree of process innovation by the frequency with which processes are introduced.

4.4.3 Research and Development Effort

The third section of the questionnaire focuses on the sources of product and process innovation. These sources are research and development (R&D) effort by the business itself, interaction with other businesses, including other group companies (where applicable), suppliers, customers and competitors, interaction with academic-based researchers and interaction with innovation supporting agencies. The questionnaire states that academic-based researchers are those based at third-level institutions or at university based research centres. Innovation supporting agencies are defined as publicly funded institutions that support R&D in businesses, through research grants and facilitating interaction.

The first series of questions in this section of the questionnaire relate to the business' R&D effort. Respondents are asked in Question C.1 whether their business undertook R&D between 2001 and 2003. If R&D was not performed the respondent is instructed to move on to Question C.6. If a respondent indicated that their business did undertake R&D, they are asked in Question C.2 to indicate whether their business had a dedicated R&D department. This question is used to indicate the extent to which R&D is a formal activity within the business. Schumpeter contends that "innovation itself is being reduced to routine" (1942:132) and this question addresses the issue of whether innovation output is positively affected by a formalization or routinisation of R&D.

Question C.3 asked respondents to indicate the average number of employees in R&D departments over the three-year period. Again respondents are asked to estimate employee numbers in terms of full-time equivalent (FTE). This is one of the variables used to construct measures of the extent of R&D effort in the business (Oerlemans, Meeus and Boekema, 2001). Another measure, following Freel (2003), is the proportion of turnover invested in R&D in the three-year period, which is the subject of Question C.4. Respondents are asked to indicate the percentage of turnover within intervals of five percentage points. Question C.5 asks about the extent of financial support for R&D that respondents received from innovation-supporting agencies as a percentage of total R&D expenditure between 2001 and 2003.

The survey sample comprises both indigenous and foreign-owned businesses. These foreign-owned businesses may be manufacturing plants of large multinational businesses and so may not have control over the location of R&D activity. Also, multinational businesses may, to benefit from knowledge spillovers, scale economies or other commercial reasons, decide to locate all R&D activity for the group in one location. Question C.6 asks respondents if their business is a parent or subsidiary whether other businesses in the group had a dedicated R&D department.

4.4.4 Interaction for Product Innovation

A potential source of knowledge for these innovations may be the business' interaction with a range of other companies or supporting institutions. Of course, those businesses that have performed R&D may also benefit from interaction for innovation. In fact, performing R&D may enhance the benefit of interaction for innovation; Cohen and Levinthal (1990) contend that businesses performing R&D develop absorptive capacity that enables them to identify and exploit external knowledge.

The remaining questions in Section C address interaction for innovation with various interaction agents, which comprise other businesses, academic-based researchers and innovation supporting agencies and the geographical proximity of these agents to the business.

Respondents are told on the questionnaire that interaction may involve meetings, networking or other communications that affect innovation in their business and that interaction may range from social or informal, perhaps unintentional, networking to formal or contractual collaboration that generates new knowledge used in product and/or process innovation.

The first question in relation to interaction, Question C.7, refers to membership of a business association or lobby group. If a business is a member of such an association it implies a level of co-operation and collaboration with other businesses in the same industry or other shared characteristics. Such membership implies openness to sharing information with other businesses, though the nature of that knowledge sharing is unclear.

Subsequent questions examine more specifically the nature of interaction for innovation. Question C.8 asked respondents to indicate the frequency of interaction with six interaction agents in relation to product innovation between 2001 and 2003. The six interaction agents are other group companies, suppliers, customers, competitors, academic-based researchers and innovation-supporting agencies. Frequency of interaction is measured on a scale from continuously, to frequently, regularly, rarely and never. This approach generates two measures of interaction. First, the incidence of interaction is a binary ‘yes/no’ measure. Second, the question also measures the frequency with which interaction takes place.

Analysing the frequency of interaction for innovation raises the issue of geographical proximity and whether businesses are more likely to interact with those businesses and institutions that are closer to them.

Geographical proximity is a difficult concept to measure in the context of a business survey. The standard approach in the literature has been to identify interaction agents by region, which in US studies may be a state or metropolitan area, (Jaffe, 1986; Acs, Audretsch and Feldman, 1992; Baptista, 2000; Anselin, Varga and Acs, 2000) and to imply that agents are geographically close if they are co-located in the same region. This approach is not adopted here. Businesses may be located close to each other even though they may be in different administrative regions. For example, Ireland is divided into seven Regional Authority Areas (RAAs). A business in Youghal in County Cork and a business in Tralee, County Kerry are located in the South-West RAA, while a business in Waterford City is located in the South-East RAA. Youghal is fifty miles and approximately one hour driving time from Waterford. Youghal is just over one hundred miles and approximately two and a half hours driving time to Tralee. If proximity has a positive effect on the frequency of interaction it is more likely, all other things being equal, for a business in Youghal to interact with businesses and academic-based researchers in Waterford than in Tralee even if the latter are co-located in the South-West RAA.

In not adopting co-location as a measure of proximity, new difficulties arise in formulating a straight-forward measure of distance that would not be easily misinterpreted and could be answered quickly by potential respondents. As with many of the questions in this survey, a balance is struck between getting maximum useful information and keeping the questions as short and easy to interpret as possible. Both distance and travel time were considered as possible measures, but both were rejected as they proved unwieldy in formulating an easily-interpreted question. Physical distance is ruled out, as it is considered that individuals consider proximity in terms of time of travel, particularly in a business context when time away from the office or time devoted to an activity, such as travelling, is important. However, a standard travel time approach is rejected as it is too difficult to distinguish between forms of travel while keeping the question short and clear. For example an interval of one to two hour travel time would include Cork to Limerick and Cork to London. As a result the approach adopted here is to use average one-way driving time to measure proximity between interaction agents.

Businesses may interact with a number of different interaction agents in each category identified so, in order to measure the role of proximity on the likelihood and frequency of interaction, businesses are asked, in Question C.9, to determine the single most important source of knowledge for product innovation in each of the interaction agent categories. Respondents are then asked to indicate the average one-way driving-time between their business and that organisation considered to be the most important source of knowledge. Driving times are categorised into five intervals, less than half and hour, half to one hour, one to two hours, two to four hours and greater than four hours. The lower end of the range represents very close proximity or co-location in a particular town or city. Four hours is a substantial driving time in the Irish context, and respondents are instructed to indicate a drive time of greater than four hours where the interaction agents are outside of Ireland. This means that the survey is unable to distinguish between interaction agents that are domestic but more than four hours driving time away and those that are abroad. This does not pose a significant problem for analysis however, since the critical consideration in subsequent analyses is whether an interaction agent is proximate or not, rather than their exact location. Those located abroad and more than four hours drive-time away can both be considered not proximate.

4.4.5 Interaction for Process Innovation

In Questions C10 and C.11, respondents are asked a similarly constructed set of questions in relation to the incidence and frequency of interaction for process innovation, and in relation to the geographic proximity of interaction agents for process innovation.

4.4.6 Competitive Environment

The final section of the questionnaire contains questions in relation to the competitive environment within which the participant's business operates. The questions are intended to shed light on the business' strategy and market power in relation to product and process innovation. This section of the questionnaire relates to the literature on market structure and innovation. A review of empirical studies in this area is presented in Cohen and Levin (1989). Most studies have used market concentration as a measure of market structure and Cohen and Levin (1989) note that a majority find evidence of a positive relationship between market concentration and R&D activity.

The sectors selected for this study are engaged in international trade and/or many of the businesses in the survey sample are Irish manufacturing operations of foreign multinationals that may sell their output to other companies in the group. For these reasons, a market concentration ratio from Irish output data would not shed light on the degree of competition in these sectors in Ireland. Thurow argues "with the growth of international trade it is no longer possible to determine whether an effective monopoly exists by looking at local market shares" (1980:20).

An alternative approach, which is adopted in this study, is to ask representatives of the businesses themselves about how they perceive the structure and competitive pressures of the markets in which they operate.

This is the focus of Section D. Question D.1 asks respondents to rate the importance of product and process innovation as a source of competitive advantage on a scale of 1 to 7, where a value of 1 means they are not important and 7 means that they are very important.

Respondents are also asked to indicate their perceptions of the degree of competition in their principal markets. In question D.2 they are asked to indicate the degree to which they believe that competition in the market for their primary product or service is intense in relation to price, product quality or all aspects. A value of 1 indicates that they strongly disagree that competition is intense and a value of 7 indicates that they strongly agree that competition is intense. A high degree of perceived competition in terms of price may indicate a competitive market structure, while higher degrees of perceived competition on product quality may indicate that product differentiation may be a strategy open to businesses.

4.5 Administering the Survey

This section presents the process of testing the method of administering the survey, constructing a survey sample and conducting the survey.

4.5.1 Pilot Testing

The purpose of pilot testing is to assess the proposed method for administering the survey, to ensure that the questions are understandable and to ensure that response scales for each question are appropriate and comprehensive.

A sample of 21 businesses was chosen from the population. Businesses are selected from each of the categories in Table 4.3 to ensure that businesses from each sector are included in the pilot test. Three businesses are selected randomly from each sector in the Enterprise Ireland database. With the exception of the *ICT* and *Engineering* sectors, two businesses are selected randomly from each sector in the IDA Ireland database. Three businesses are selected randomly from these two named sectors they are larger than the others.

The pilot test was conducted between June 28 and July 20, 2004. The selected businesses were contacted by telephone. The purpose of prior contact with the target respondent is to introduce the survey and its objectives and to ask whether the respondent would prefer to receive the questionnaire by post or electronically by email. Of the 21 businesses contacted, 8 (38%) chose the electronic version. In 10 (48%) cases the individual contact was not spoken to before the questionnaire was sent by post, but messages were left to inform them that a questionnaire would be sent. No potential respondent indicated at this stage that they were unwilling to complete the questionnaire.

Without follow-up, 2 responses were received. Both of these were completed electronically and returned by email. These were from businesses in the Enterprise Ireland database and both were in the *Electronic and Electrical Equipment* sector. One of those responses was returned as email text, so that part of the questionnaire was not readable. The other response was sent as an attachment and was fully readable.

First follow-up involved contacting non-respondents by telephone to remind them of the survey and request completion. This resulted in one more response. This respondent returned the questionnaire by post. This respondent was from the *Chemicals and Pharmaceuticals* sector in the Enterprise Ireland database. Two further responses were received after the period of the pilot test when the final survey instrument was being administered. These responses are not included in the survey sample.

To evaluate the structure of the questionnaire and the clarity of questions and to explain item non-response, two respondents were contacted by telephone. The third respondent was on leave and not contactable. These respondents provided comments on the time required to complete the questionnaire and whether the questions and instructions were easily understood.

Based on the pilot test several changes in the procedure and/or questionnaire were taken. These included clearer instructions on returning electronic versions of completed questionnaires, to ensure that returned surveys are readable, and shorter periods of time between sending the survey and initial and subsequent follow-ups. The only changes to the wording of the questions came in relation to the proximity questions (C.9 and C.11), in which the wording was amended to request the respondent to initially identify the single most important source of knowledge and then indicate the average one-way driving time to that source. This change made the question easier to understand.

4.5.2 Administering the Survey

Prior to sending a copy of the questionnaire, a senior executive in each business was contacted by telephone. The purpose of this contact was to introduce the study, identify an appropriate point of contact and to seek permission to send the questionnaire. Many businesses contacted referred to the large number of survey questionnaire they receive, both from government agencies and academic researchers. One respondent stated that he had received a dozen questionnaires in the week he was contacted for this survey. Many respondents indicated that they appreciated the practice of this survey of contacting them initially to introduce the study and explain the objectives. A copy of the survey questionnaire was posted or emailed to the potential respondent according to their preference. Postal and email reminders were also sent approximately one week and three weeks after the questionnaire was first sent.

The Enterprise Ireland database provides substantial detail on each business, including address, telephone number, number of employees within specified interval ranges, export markets, brand names, product categories and sub-categories and contact names and titles. The contact names generally included Managing Director or equivalent, and in some cases Business Development and/or Finance Managers. The IDA Ireland database provided only company name and address and website links. The Kompass Directory of Irish Industry and the Irish Times Top 1000 Companies databases are used to identify potential contact names and telephone numbers in these businesses. In each case the preferred contact was at Managing Director level, though where those are not available, business development managers are contacted. The questionnaire requires a respondent to have broad knowledge of the business. Business development managers are considered to be aware of activities across the functions of their business. The individuals contacted are informed of the purpose of the study and asked to complete the survey at their earliest convenience.

One week after the surveys were circulated non-respondents were contacted by telephone to remind them of the questionnaire. One week later, non-respondents were sent reminder emails or letters, depending on how the questionnaire was originally sent.

There were approximately 600 man-hours employed in designing and testing the survey instrument, constructing the database of businesses and administering the survey between May and December 2004. This resulted in 184 usable responses, corresponding to a response rate of 21.5%. The response rate by sector is presented in Table 4.5.

Table 4.5 – Response Rate by Sector (number of businesses)

	Population	Responses	Response Rate %
Chemicals and Pharmaceuticals Sector			
Pharmaceuticals (IDA Database)	68	17	25.0%
Chemicals (IDA Database)	18	7	38.9%
Chemicals and Pharmaceuticals (EI Database)	97	19	19.6%
Sub-Total	183	43	23.5%
ICT Sector			
ICT (IDA Database)	129	19	14.7%
Computers, Software and Consultancy (EI Database)	222	46	20.7%
Sub-Total	351	65	18.5%
Electronics Devices and Engineering			
Medical Devices (IDA Database)	53	12	22.6%
Engineering (IDA Database)	103	19	18.4%
Electronic and Electrical Equipment (EI Database)	167	44	26.3%
Sub-Total	323	75	23.2%
Anonymous		1	
Total	**857**[1]	**184**	**21.5%**

Source: www.idaireland.com; www.enterprise-ireland.com/sourceirelandsearch; Author's survey

Notes:

1. The total population is 878 businesses, though 21 were used to pilot test the survey and so are excluded from the study itself.

Given the comprehensive nature of the survey the response rate is satisfactory. It has been observed that there is a growing survey response burden on Irish businesses

(CSO, 2001; Forfás, 2005:31) and, indeed, many of the target respondents contacted in the course of this survey were critical of the number of survey requests received.

The response rate in this study compares favourably with response rates achieved in other innovation studies. Roper (2001) achieved an overall response rate of 33%, with 29% for Republic of Ireland businesses. Harris and Trainor (1995) also report a response rate of 33%. Other response rates in innovation studies include 24% for Madill, Haines and Riding (2004), 20% for both Nieto and Quevedo (2005) and Andreosso-O'Callaghan (2000), 11.5% for Freel (2003) and 8% for Oerlemans (2001).

The response rate achieved in this survey, 184 observations, is sufficient to produce meaningful results from the descriptive statistics presented in Chapter 5 and econometric analyses presented in Chapters 6 and 7.

4.5.3 Representativeness of the Survey Sample

There is no reason to believe that the databases used to construct the survey sample include all of the businesses in the sectors under consideration. It is likely that all foreign-owned businesses in these sectors are included in the IDA Ireland list, since these businesses are likely to benefit from financial assistance in locating in Ireland, and so would be known to IDA Ireland. There is potential for self-selection bias in relation to the Enterprise Ireland register of businesses, as businesses may not be aware of the SourceIreland service if they do not have contact with Enterprise Ireland or may elect not to register on the website.

Table 4.6 shows that there are businesses in the population not included in the survey database. Two sources are used to estimate the population of businesses in the selected sectors. The Census of Industrial Production 2002 (CSO, 2003) reports the number of local units by NACE code. This is the most recently published census. The number of local units reported for NACE code 2233 (Reproduction of Computer Media) and NACE code 30 (Manufacture of Office Machinery and Computers) is lower than the number of businesses in the *ICT* sector of the survey database. This is because the CIP relates to businesses engaged in industrial activity. Since software businesses, which are included in the survey database, are considered service businesses they would be outside of the CIP. The National Software Directorate (NSD) (www.nsd.ie), which maintains a database of software businesses in Ireland is used to supplement the CIP in generating the population of Irish high-technology sectors.

Table 4.6 shows a comparison between the number of businesses in the population and the number of businesses in the survey database.

It can be seen from Table 4.6 that the survey sample includes 38% and 39% of businesses in the Electronic Devices and Engineering and ICT sectors respectively. The coverage in the *Chemicals and Pharmaceuticals* sector is higher, with 73% of businesses included.

Since there is no database for the population comparable to that created for the sample frame, common variables must be identified to enable a comparison between the two databases. Two variables used here, which are available from the Census of Industrial Production 2002 (CSO, 2003) and NSD are nationality of ownership and employment.

Table 4.6 – Survey Coverage of Population by Major Sector (number of businesses)

	NACE Code[1]	Number of Units in Population[2]	Number of Businesses Surveyed[3]
Electronic Devices and Engineering	29, 352 + 359, 34, 31, 33, 32	846	323 (38%)
ICT	30, 2233, NSD	900[4]	351 (39%)
Chemicals and Pharmaceuticals	24	250	183 (73%)

Source: www.idaireland.com; www.enterprise-ireland.com/sourceirelandsearch; CSO (2003); www.nsd.ie;

Notes:
1. The NACE codes for each sector are based on the OECD classification presented in Table 4.1.
2. This is the number of local units in the NACE code categories identified (CSO, 2003)
3. Percentages in parentheses refer to the percentage of the total population.
4. The Census of Industrial Production (2002) states there are 29 local units in NACE Code 2233 (Reproduction of Computer Media). The National Software Directorate (NSD) (2003) states that there are almost 900 businesses in the Irish software industry, 760 of which are indigenous. For this table it is assumed that the 29 local units in NACE Code 2233, as well as the local units included in NACE Code 30, are included in the NSD's 900 businesses.

First, Table 4.7 presents a comparison between the population and the sample frame by nationality of ownership. The published data from the Census of Industrial Production (CIP), 2002 did not provide sufficient detail to construct Table 4.7, so the data presented is based on a specific request to the Central Statistics Office. This data was restricted for confidentiality purposes by the Central Statistics Office so that certain NACE classification codes were amalgamated in the data provided.

Table 4.7 – Sample Representativeness: Indigenous and Foreign-Owned Businesses

	Population	Survey
Electronic Devices and Engineering[1]		
Indigenous	73%	55%
Foreign	27%	45%
ICT[2]		
Indigenous	80%	62%
Foreign	20%	38%
Chemicals and Pharmaceuticals[3]		
Indigenous	51%	37%
Foreign	49%	63%
Total		
Indigenous	74%	53%
Foreign	26%	47%

Notes:

1. This includes NACE codes 29, 352+359, 34, 31, 33, 32, which corresponds to those identified as medium-high and high-technology sectors in the OECD classification set out in Table 4.3. The Census of Industrial Production, 2002 reports activity for NACE codes 352 to 355 inclusive. There is no activity in the census for NACE code 359.
2. This includes NACE codes 30, which is considered a high-technology sector in the OECD classification set out in Table 4.3. NACE Code 2233 (Reproduction of Computer Media) is also included, as well as businesses in the software industry as reported by the National Software Directorate (2003)
3. This includes NACE code 24, corresponding to those identified as medium-high and high-technology sectors in the OECD classification set out in Table 4.3.

It can be seen from Table 4.7 that overall the survey sample appears to be under-representative of indigenous businesses. In each sector the population has a higher percentage of indigenous businesses than the survey sample. The total sample is more evenly split between indigenous and foreign-owned businesses than the population, which has a three to one ratio of indigenous to foreign-owned. It was noted earlier that foreign-owned businesses register with IDA Ireland to avail of financial assistance, so the IDA Ireland database used for this study is likely to include most of the foreign-owned businesses in the population. The Enterprise Ireland database used in this study requires indigenous businesses to register on it. Since some may not be aware of the database or may not want to register, a greater proportion of indigenous businesses in the population is not included on the database for this study compared to foreign-owned businesses. This may explain the under-representativeness of indigenous businesses in the sample.

The representativeness of the sample is also assessed based on average employment. Table 4.8 shows the average employment in the population and the survey sample, as well as the 95% confidence interval of the survey mean and the survey sample 5% trimmed mean. These are presented by sector.

It can be seen from Table 4.8 that in each sector average employment is higher in the sample than it is in the population, indicating that the sample is under-representative of smaller businesses. However, the population mean employment is within the 95% confidence interval for the survey mean for each sector.

Adopting a 5% trimmed mean, average employment in the sample is close to the population levels, particularly for the *ICT* and *Electronic Devices and Engineering* sectors. This suggests that there may be a small number of very large businesses pulling the average employment levels upwards.

Table 4.8 – Sample Representativeness: Average Employment (number of full-time equivalent employees)

Sector	*Population Average Employment* [1]	*Survey Average Employment*	*95% Interval for Survey Mean*	*Survey 5% Trimmed Mean*[2]
Electronic Devices and Engineering[3]	75	118	73 - 161	86.1
ICT[4]	45	61	38 - 62	46.7
Chemicals and Pharmaceuticals[5]	118	191	98 - 282	144
Total	65	115	85 - 143	83

Notes:

1. The average employment in the population is total employed divided by the number of local units reported in the Census of Industrial Production, 2002 (CSO, 2003). This refers to employment in 2002, though the survey measures employment at the end of 2003.
2. The trimmed mean is the average excluding the highest 2.5% employment and the lowest 2.5% employment.
3. This includes NACE codes 29, 352+359, 34, 31, 33, 32, which corresponds to those identified as medium-high and high-technology sectors in the OECD classification set out in Table 4.3. The Census of Industrial Production, 2002 reports activity for NACE codes 352 to 355 inclusive. There is no activity in the census for NACE code 359.
4. This includes NACE codes 30, which is considered a high-technology sector in the OECD classification set out in Table 4.3. NACE Code 2233 (Reproduction of Computer Media) is also included, as well as businesses in the software industry as reported by the National Software Directorate (2003)
5. This includes NACE code 24, corresponding to those identified as medium-high and high-technology sectors in the OECD classification set out in Table 4.3.

4.6 Potential Non-Response Bias

Non-response introduces potential for bias to a survey sample. There are two types of non-response to consider. The first, survey non-response, arises when targeted respondents do not return the questionnaire. The second type of non-response is item non-response, which occurs when a questionnaire is returned with some questions left unanswered. This may be due to an oversight by the respondent or unwillingness to answer a question, perhaps because it is sensitive to the business or the respondent does not know the answer to the question.

4.6.1 Survey Non-Response

It was seen in Table 4.5 that the response rate for the survey is 21%. As a result there is potential for response rate bias, which would result from significant differences between non-respondents and respondents. Since this study is concerned with explaining innovation activity, it is particularly important to test whether there is a difference in innovation activity between businesses that responded and those that did not and to ensure that the sample frame is not over-representative of innovative businesses. To check the representativeness of respondents in relation to the level of innovative activity, a random sample of 92 non-respondents was contacted by telephone and asked about their innovation activity. Following Breathnach (1996) non-respondents are asked three questions based on questions contained in the questionnaire. These questions are:

1. Did your businesses introduce new products/services to the market between 2001 and 2003?
2. Please indicate the extent to which your business introduced new processes between 2001 and 2003. (Respondents are asked to select from a five point scale from continuously to frequently, regularly, rarely and never).
3. Did your business undertake R&D between 2001 and 2003?

In each case the definitions of product and process innovation are quoted from the survey questionnaire.

Table 4.9 presents the sectoral break-down of the 92 non-respondents contacted.

Table 4.9 – Comparison of Sample Frame and Non-Respondents by Sector: number of businesses (percentages in parentheses[1])

	Sample Frame	Non-Respondents
Chemicals and Pharmaceuticals Sector		
Pharmaceuticals (IDA Database)	17 (9%)	8 (9%)
Chemicals (IDA Database)	7 (4%)	4 (4%)
Chemicals and Pharmaceuticals (EI Database)	19 (10%)	9 (10%)
Sub-total	43 (23%)	21 (23%)
ICT Sector		
ICT (IDA Database)	19 (10%)	10 (11%)
Computers, Software and Consultancy (EI Database)	46 (25%)	23 (25%)
Sub-total	65 (36%)	33 (36%)
Electronics Devices and Engineering		
Medical Devices (IDA Database)	12 (7%)	6 (7%)
Engineering (IDA Database)	19 (10%)	10 (11%)
Electronic and Electrical Equipment (EI Database)	44 (24%)	22 (24%)
Sub-Total	75 (41%)	38 (41%)
Total	**183**[2] (100%)	**92** (100%)

Notes:

1. The percentage of the total number of businesses surveyed. Percentages may not to sub-totals due to rounding.
2. The total number of responses is 184, but one response is anonymous and could not be allocated to a sector.

The proportion of non-respondents in each sector is identical to the proportions in the sample frame. Non-respondents are randomly selected from each sector. Where businesses could not be contacted, an alternative from the same sector is randomly selected until the required number of businesses from that sector is contacted. No business contacted refused to answer the three questions.

Table 4.10 compares responses to the three questions for the sample frame and non-respondents. Pearson's Chi-Square test is used to test for significant differences in the rate of product innovation, process innovation and R&D between businesses in the sample frame and non-respondents. This is the most common type of chi-square test and is used to test the hypothesis of no association of columns and rows in tabular data. A chi-square probability value of less than 0.05 (or 0.025 for a two-tailed test) is interpreted as justification for rejecting the null hypothesis that a row variable is only randomly related to the column variable at a 95% confidence level. In this case a chi-square probability value of less than 0.025 would indicate that the column variable (for example, the percentage of product innovators) is related to the row variable (in this case whether the business is part of the sample frame or is a non-respondent).

Table 4.10 – Comparison between Sample Frame and Non-Respondents: number of businesses (percentages in parentheses)

Variable	Sample Frame (n=183)	Non-Respondents (n=92)	Test Statistic	P-Value[1]
Product Innovators[2]	147 (80%)	70 (76%)	Pearson Chi-Square=0.662, d.f.=1	P=0.416
Regular Process Innovator[3]	137 (75%)	67 (73%)	Pearson Chi-Square=0.133, d.f.=1	P=0.716
Performing R&D[4]	122 (67%)	55 (60%)	Pearson Chi-Square=1.265, d.f.=1	P=0.261

Notes:

1. This is a two-tailed test of significance.
2. The number of businesses that indicated they had introduced at least one new product/service in the three years between 2001 and 2003.
3. The number of businesses that introduced new processes on at least a regular basis between 2001 and 2003.
4. The number of businesses that performed R&D between 2001 and 2003.

For all three variables, tests of equality in the percentage of business in each across sectors could not be rejected, suggesting there is no statistical evidence of a difference in the percentage of product innovators, regular process innovators and businesses performing R&D between those businesses that responded to the survey and those that did not (in each case the chi-square probability value is greater than 0.025). The results presented in Table 4.10 indicate that bias from survey non-response is not a problem in this study.

4.6.2 Item Non-Response

Table 4.11 presents response rates by question. The table shows the number of respondents by question. It also shows the valid percentage of respondents, which is the percentage of businesses for which a question is applicable that actually answered that question. For example, the question on turnover from new products could only be answered by respondents that indicated that their businesses had introduced new products or services in the three years to 2003. This explains a 100% response rate to the question on turnover from new products even though it is not answered by all survey respondents.

Table 4.11 – Item Response Rates

Business Characteristics

	Age in Years	Number of Products	Employment 2001	Employment 2003	% of Employees with 3rd Level	Profitability	Sales Growth
Frequency	184	184	184	184	184	167	179
Percent	100%	100%	100%	100%	100%	91%	97%

Innovation Output Indicators

	Product Innovator	Turnover from New Products	Frequency of Process Innovation
Frequency	184	147	184
Percent	100%	100%	100%

R&D Activity

	Perform R&D	R&D Function	R&D Employment	R&D Expenditure	Funding for R&D	R&D in other Group Company
Frequency	184	123	76	123	127	104
Percent	100%	100%	100%	100%	100%	98%

Interaction for Product Innovation

	Business Association Membership	Interaction with Group for Product Innovation	Interaction with Suppliers for Product Innovation	Interaction with Customers for Product Innovation	Interaction with Competitors for Product Innovation	Interaction with Academics for Product Innovation	Interaction with Agencies for Product Innovation
Frequency	184	101	184	182	182	181	182
Percent	100%	95%	100%	99%	99%	98%	99%

Table 4.11 continued – Item Response Rates

Proximity for Product Innovation

	Proximity to Group Interaction Agent	Proximity to Supplier Interaction Agent	Proximity to Customer Interaction Agent	Proximity to Competitor Interaction Agent	Proximity to Academic Interaction Agent	Proximity to Agency Interaction Agent
Frequency	85	139	153	89	90	102
Percent	90%	86%	90%	83%	83%	83%

Interaction for Process Innovation

	Interaction with Group for Process Innovation	Interaction with Suppliers for Process Innovation	Interaction with Customers for Process Innovation	Interaction with Competitors for Process Innovation	Interaction with Academics for Process Innovation	Interaction with Agencies for Process Innovation
Frequency	97	180	180	179	178	178
Percent	92%	98%	98%	97%	97%	97%

Proximity for Process innovation

	Proximity to Group Interaction Agent	Proximity to Supplier Interaction Agent	Proximity to Customer Interaction Agent	Proximity to Competitor Interaction Agent	Proximity to Academic Interaction Agent	Proximity to Agency Interaction Agent
Frequency	84	134	129	74	80	88
Percent	90%	91%	90%	97%	100%	99%

Competitive Environment

	Importance of Product Innovation for Competitive Advantage	Importance of Process Innovation for Competitive Advantage	Degree of Competition in all Aspects	Degree of Competition in Price	Degree of Competition in Quality and Specification
Frequency	183	182	181	182	181
Percent	99%	99%	98%	99%	98%

It can be seen from Table 4.11 that most questions in relation to business characteristics are answered by all respondents. Two respondents did not answer the question in relation to the age of their business and two other respondents did not indicate employment levels. This data is available from the business' website, the Kompass Directory (2004) and the Irish Times List of Top 1000 Companies (2004). The profitability question is not answered by 17 (9%) respondents and this information is not available from other sources. There are 5 (3%) non-responses in relation to sales growth and, again, this information is not available from other sources.

Innovation output questions, Section B in the questionnaire, are fully answered. Questions on R&D activity are also answered by all respondents.

Questions in relation to interaction for product and process innovation have very high response rates. Initially, approximately 10 to 12 respondents did not answer questions in relation to interaction. These were contacted by telephone and most gave their answers at that stage. The remaining non-responses were not contactable or did not respond to follow-up calls.

The proximity questions emerge as the group of questions with the lowest average response rates, though the response rate on this questions is over 80% which suggests this is not a significant problem. The response rates reported in Table 4.11 include those respondents that provided an answer after follow-up by telephone. Some non-respondents were not contactable subsequently or did not respond to follow-up requests. The most common explanations for non-response to these questions were first that they came towards the end of the questionnaire and respondents were anxious to finish the questionnaire and second respondents found it difficult to identify just one interaction agent in each category that is most important in terms of interaction for innovation.

Questions in Section D of the questionnaire in relation to the business' competitive environment are generally well answered. The reported level of response is achieved by contacting 14 initial non-respondents.

4.7. Conclusion

This Chapter has presented the design, construction, testing and implementation of a survey instrument used to gather original data on innovation activities in Irish high-technology sectors. The discovery of this data is an important contribution to empirical work on innovation as Sena who, in identifying a lack of appropriate data as the major problem underlying research on knowledge spillovers, called for an "innovation database based on survey information which could provide business-specific data on spillovers" (2004:328).

The variables generated by the survey that are used in the analyses reported in subsequent Chapters are set out in Appendix 2, which also contains the coding of survey responses.

Chapter 5 presents statistical descriptive analysis of the data generated by the survey described in this Chapter. Statistical analysis of the survey results sheds light on the levels of product and process innovation, R&D activity, the frequency of interaction for innovation and the spatial dispersion of that interaction for different sectors, nationality of ownership, ages and sizes of Irish high-technology businesses. The survey data is used in Chapter 6 to estimate a series of innovation production functions, that model product and process innovation as a function of R&D and interaction, while controlling for relevant business characteristics. This Chapter explores the relative importance of each factor as a driver of innovation output. The results have important policy implications, which are discussed in detail at the end of the Chapter. Chapter 7 is concerned with the spatial dispersion of interaction for innovation. Discriminant analysis is used to identify differences in innovation output, R&D activity and the frequency of interaction across different categories of geographic distance between interaction agents. The effect of geographic proximity on the frequency of interaction with each interaction agent is estimated using an ordered probit estimation technique. The Chapter also investigates the effect on product and process innovation of a business' location in urban areas, based on additional secondary data.

Finally, Chapter 8, summarises the key findings from each of the previous three Chapters and considers the implications of these findings for Irish industrial, enterprise, innovation and regional policies.

CHAPTER 5: THE EFFECTS OF INTERACTION AND PROXIMITY ON INNOVATION IN IRISH HIGH-TECHNOLOGY BUSINESSES - SURVEY RESULTS AND POLICY IMPLICATIONS

Chapter 4 presents the survey design and instrument used to construct a database on innovative activity in Irish high-technology businesses. This is the first dedicated survey of the drivers of innovation in these important sectors. This is the first Chapter to report survey results. Chapter 5 reports descriptive analyses of the survey data and discusses policy implications from the survey results, which instruct the inferential analysis that follows in Chapters 6 and 7.

This Chapter is structured as follows. The first section presents the characteristics of businesses in the survey, including average employment, age, employee educational attainment, the number of products or services offered to the market, profitability and sales growth. These characteristics are analysed by sector and by nationality of ownership. The second section presents innovation output indicators, again by sector and nationality of ownership. This includes measures of the incidence and extent of both product and process innovation. The third section considers sources of innovation, presenting results on research and development activity and interaction for product and process innovation with various interaction agents. Comparisons of the incidence and frequency of interaction are made across sectors and nationality of ownership. This section also presents similarities and differences in the pattern of interaction for businesses that do or do not innovate. The fourth section presents results on respondents' perceptions of the intensity of competition in their primary markets. Relationships between the rate of innovation and the perceived level of competition are explored. These sections generally follow the sequence of questions in the survey questionnaire, which is discussed in Chapter 4 and is included in Appendix 1. Based on the statistical descriptive analysis reported in this Chapter, the final section summarises the important conclusions and considers the implications for Irish policy makers.

5.1 Characteristics of the Business

The first section of the survey questionnaire asked respondents about their businesses. Question A.1 asked respondents whether their business is a member of a group of companies or a stand-alone business. If applicable, respondents are asked to identify, in Question A.2, the country in which the group headquarters is located.

Table 5.1 sets out the percentage of businesses in each ownership category. It can be seen that 106 (58%) businesses are members of a group of companies, whether as parent or subsidiary.

Table 5.1 - Respondents by Ownership Structure (number and percentage of respondents)

	Frequency	Percent
Stand-alone	78	42%
Parent	18	10%
Subsidiary	88	48%
Total	184	

Source: Author's survey

Not all subsidiary businesses have foreign parent companies, as some are indigenous. The proportion of indigenous and foreign-owned businesses is set out in Table 5.2.

Table 5.2 - Respondents by Nationality (number and percentage of respondents)		
	Frequency	Percent
Indigenous	98	53%
Foreign-Owned	86	47%
Total	184	

Source: Author's survey

The respondents are almost equally split between indigenous Irish businesses and the Irish operations of a foreign multinational, with just over half of the businesses (53%) Irish owned. Table 5.3 sets out the nationality of foreign-owned businesses.

Table 5.3 - Nationality of Foreign-Owned Businesses (number and percentage of respondents)		
	Frequency	Percent
North America	36	42%
United Kingdom	17	20%
Rest of European Union	26	30%
Other	7	8%
Total	86	

Source: Author's survey

Exactly half of the subsidiary companies in the sample have headquarters located in the European Union. The other common location for headquarters of Irish subsidiary businesses is North America, and of the 36 (42%) North American, the majority is located in the United States.

Questions A.3 to A.6 asked respondents a series of questions relating to the nature of their business. Summary results of these questions by sector and by ownership type are presented in Table 5.4 and Table 5.5.

Question A.3 asked respondents when their businesses began operations in Ireland. Respondents are asked in Question A.4 the number of products and/or services it provided to the market at the end of 2003. Respondents are asked in Question A.5 to estimate the number of employees in their business at the start and at the end of the reference period. Question A.6 asked respondents to estimate the percentage of the business' workforce that possess a third-level degree or similar technical qualification.

Table 5.4 – Business Characteristics by Sector: Mean Response (Standard Deviations in Parentheses)

	Sector					
Variable	**Elec. Devices (n=75)**	**ICT (n=65)**	**Chems./ Pharm. (n=43)**	**Total (n=183)[1]**	**Test Statistic**	**P-Value[2]**
Employment 2001 (number)[3]	114.6 (196.51)	75.7 (136.88)	170.0 (260.23)	113.8 (198.0)	$F_{(2,180)}$stat= 3.005	P=0.052
Employment 2003 (number)[4]	117.8 (190.55)	60.7 (89.19)	190.6 (298.40)	114.6 (201.3)	$F_{(2,180)}$stat= 5.684	P=0.004
Education (percent)[5]	29.0 (29.30)	65.3 (32.38)	30.0 (23.34)	42.1 (33.8)	$F_{(2,180)}$stat= 31.770	P=0.000
Age (years)[6]	19.5 (15.86)	11.7 (19.39)	25.47 (18.44)	18.2 (18.5)	$F_{(2,180)}$stat= 8.102	P=0.000
Number of Products (number)[7]	86.4 (156.49)	39.8 (175.22)	69.3 (105.99)	65.8 (154.2)	$F_{(2,180)}$stat= 1.611	P=0.202

Source: Author's survey

Notes:
1. The total number of respondents is 183 as one respondent answered anonymously, so it is not possible to identify the sector to which this respondent belongs.
2. This is a two-tailed test of significance.
3. The number of employees (full-time equivalent) at the start of 2001.
4. The number of employees (full-time equivalent) at the end of 2003.
5. The percentage of the workforce that has a third-level degree or similar technical qualification.
6. The number of years from the start of operations in Ireland to the start of 2001.
7. The number of products/services offered by the business to the market at the end of 2003.

Table 5.4 presents average employment in 2001 and 2003, percentage of employees with third-level qualifications, business age and the number of products offered to the market for each sector. One-way Analysis of Variance (ANOVA) is used to test whether there is a statistical difference in the mean of each variable across sectors. One-way ANOVA is appropriate because in each case there is one dependent variable. ANOVA relies on the F distribution to test the null hypothesis that the variances of the means for each category are equal. This method is used to test for variance in means across three or more groups (Fink, 1995). An F-statistic probability value of less than 0.05 ($p<0.05$) is interpreted as justification for rejecting the null hypothesis that the variances are equal and there is no statistical difference in the means across categories at a 95% confidence level. This test is used in subsequent tables to test for differences in means between three or more groups.

Table 5.4 suggests that, on average, businesses in the *ICT* sector tend to be smaller, as measured by the number of employees. The average size of business is clearly highest in the *Chemicals and Pharmaceuticals* sector. This result is found to be significant for 2003 and only marginally outside the 95% confidence level for 2001. Businesses in the *ICT* sector also tend, on average, to have a larger proportion of their employees (65%) educated to the level of degree or similar technical qualification; the average percentage is more than double that in the *Chemicals and Pharmaceuticals* sector (30%). A test of the equality of mean educational attainment across sectors is rejected (as the p-value is less than 0.025). Businesses in the *ICT* sector are significantly younger on average (11.7 years) ($p<0.025$). While the *ICT* sector also seems to offer fewer products or services to the market than other sectors, a test of equality in means could not be rejected at the 95% confidence level ($p>0.025$).

Table 5.5 presents the same range of business characteristics categorised by nationality of ownership. In this table the Independent Samples t-test is used to test for difference in means for each variable. This is the appropriate test for difference in mean between two groups (in this case indigenous and foreign-owned businesses). For each variable a two-tail test of significance is used, so a t-statistic probability value of less than 0.025 ($p<0.025$) justifies rejecting the null hypothesis that there is no statistical difference in the means across categories at a 95% confidence level. This test is used in subsequent tables to test for differences in means between two groups.

Table 5.5 – Business Characteristics by Ownership: Mean Response (Standard Deviations in Parentheses)

	Ownership				
Variable[1]	**Indigenous (n=98)**	**Foreign-Owned (n=86)**	**Total (n=184)**	**Test Statistic**	**P-Value[1]**
Employment 2001 (number)[2]	45.9 (71.17)	190.13 (258.84)	113.3 (197.52)	$t_{(182)}$stat= - 5.296	P=0.000
Employment 2003 (number)[3]	48.9 (65.57)	188.6 (267.20))	114.2 (200.8)	$t_{(182)}$stat= - 5.009	P=0.000
Education (percent)[4]	52.7 (35.25)	30.6 (28.09)	42.4 (33.9)	$t_{(182)}$stat= 4.659	P=0.000
Age (years)[5]	15.8 (18.88)	20.8 (17.63)	18.1 (18.4)	$t_{(182)}$stat= -1 .859	P=0.065
Number of Products (number)[6]	34.4 (71.17)	101.17 (206.71)	65.5 (153.8)	$t_{(182)}$stat= - 3.014	P=0.003

Source: Author's survey

Notes:
1. This is a two-tailed test of significance.
2. The number of employees (full-time equivalent) at the start of 2001.
3. The number of employees (full-time equivalent) at the end of 2003.
4. The percentage of the workforce that has a third-level degree or similar technical qualification.
5. The number of years from the start of operations in Ireland to the start of 2001.
6. The number of products/services offered by the business to the market at the end of 2003.

Indigenous businesses tend, on average, to be smaller in both years and also display a higher percentage of employees educated to degree level. These businesses also offer fewer products or services to the market. Tests of the null hypotheses for equality of means for these variables are rejected in each case at a 95% confidence level ($p<0.025$). A test for equality of mean age for both categories cannot be rejected ($p>0.025$), though this is marginal at the 90% confidence level.

Respondents are asked about their business' performance from 2001 to 2003 in terms of profitability and growth in turnover. The profitability of respondents is presented in Table 5.6 by sector. To test for significant differences in the profitability of businesses across sectors Pearson's Chi-Square test is used. This is used to test for difference in means for three variables between the sample frame and non-respondents in Table 4.10 in the previous Chapter. Profitability is measured using an interval range. This means it is reported in tabular format and a chi-square test is appropriate. A chi-square probability value of less than 0.05 (or 0.025 for a two-tailed test) is interpreted as justification for rejecting the null hypothesis that a row variable is only randomly related to the column variable at a 95% confidence level. In this case a chi-square probability value of less than 0.025 would indicate that profitability is related to sector or ownership. This test is used in all subsequent tests of association in tabular data.

Table 5.6 also reports the skewness of the distribution of responses by sector and ownership. Skewness describes the symmetry of a distribution around its means. A positive skewness statistic indicates observations clustered at the lower end of the range of values. A negative skewness statistic indicates observations clustered at the upper end of the range of values

Table 5.6 – Profitability by Sector and Ownership

	Modal Category	**Percent not in Modal Category**	**Skewness**[1]
Sector			
Electronic Devices and Engineering	0 to 10%	57%	0.838 (0.287)
ICT	Not in profit	55%	0.861 (0.309)
Chem/Pharm	0 to 10%	47%	1.365 (0.393)
Ownership			
Indigenous	0 to 10%	58%	0.926 (0.254)
Foreign-Owned	0 to 10%	61%	0.877 (0.274)
Total[2]	0 to 10%	59%	0.924 (0.188)

Source: Author's survey

Notes:
1. The numbers in parentheses are standard errors.
2. The total response for the question on profitability is 167 businesses (91%). For the sectoral classification the total response is 166 businesses, as one respondent replied anonymously and cannot be categorized by sector.

This table indicates that most businesses have low profit margins, as the modal category in each sector is either a loss or a profit margin of 0 to 10%. For both indigenous and foreign-owned businesses the modal category of profitability is 0 to

10%. Each sector and both categories of ownership are highly positively skewed, implying a clustering of responses in the lower range of profit margins.

A test of equality in the proportions across sectors is rejected at a 90% confidence level ($P<0.05$), suggesting businesses in the *ICT* sector are more likely to experience a loss or low levels of profitability in 2003 than businesses in the other sectors [Pearson's Chi-square =20.076, degrees of freedom(df)=10, p-value = 0.029]. The probability value is only marginally insignificant at the 95% level of confidence. A test of equality of proportions for indigenous and foreign-owned businesses could not be rejected, suggesting there is no statistical evidence of a difference in profitability between these categories of business [Pearson's Chi-square =8.053, df=5, p-value = 0.153]. The lower level of profitability observed in the *ICT* sector may reflect the younger age profile of businesses in this sector in the sample, as reported in Table 5.4, or it may arise from the downturn in high-technology sectors internationally in the early years of this decade.

Question A.8 asks respondents to indicate the rate of growth in sales in the three years between 2001 and 2003 and the results are shown by sector in Table 5.7.

Table 5.7 – Sales Growth by Sector and Ownership

	Modal Category	**Percent not in Modal Category**	**Skewness[1]**
Sector			
Electronic Devices and Engineering	0 to 10%	60%	1.787 (0.281)
ICT	0 to 10%	77%	0.884 (0.299)

Chem/Pharm	0 to 10% 15 to 20%[2]	70%	1.846 (0.369)
Ownership			
Indigenous	0 to 10%	76%	1.224 (0.247)
Foreign-Owned	0 to 10%	61%	1.639 (0.263)
Total[3]	0 to 10%	69%	1.390 (0.182)

Source: Author's survey

Notes:
1. The numbers in parentheses are standard errors.
2. Two categories had an equal frequency. Both 0 to 10% and 11% to 20% had 12 (30%) respondents in that sector.
3. The total response for the question on sales growth is 179 businesses (97%). For the sectoral classification the total response is 178 businesses, as one respondent replied anonymously and cannot be categorized by sector.

The modal category (0 to 10%) for growth in sales from 2001 to 2003 is consistent across sectors and nationality of ownership. A test of the null hypothesis of equality in proportions is rejected at a 95% confidence level [Pearson's Chi-square =31.080, df=20, p-value = 0.054], though this is only marginally insignificant at a 90% confidence level.

The degree of skewness is positive for all sectors, though it is lowest for the *ICT* sector, which means that businesses in the *ICT* sector are less clustered at lower levels of sales growth compared to the other two sectors.

The Chi-square statistic probability value is insignificant for indigenous and foreign-owned businesses, [Pearson's Chi-square =9.649, df=10, p-value = 0.472] which indicates that the null hypothesis of equal rates of sales growth is rejected. This implies that indigenous businesses experienced higher rates of growth in sales between 2001 and 2003 than foreign-owned businesses.

5.2 Innovation Output Indicators

The second section of the questionnaire related to the respondent's innovation performance in the three years to the end of 2003. The questionnaire considers both product and process innovation.

5.2.1 Product Innovation

Question B.1 asked respondents how many new goods and/or services their business introduced to the market between 2001 and 2003. The introduction of any new goods and/or services means that the participant business is characterised as a product innovator. Respondents are also asked, in Question B.2, to estimate the percentage of business turnover in the three years to the end of 2003 generated by the newly introduced goods and/or services. Tables 5.8 to 5.11 show the incidence of product innovation and innovation performance by sector, ownership category, age and size.

Table 5.8 shows the incidence of product innovation and the percentage of turnover in 2003 attributable to new products and services by sector. One-way ANOVA is used to test whether there is a statistical difference in the mean turnover attributed to new products across sectors.

Table 5.8 – Product Innovation by Sector
Sector

Variable	Elec. Devices (n=75)	ICT (n=65)	Chem./ Pharm. (n=43)	Total (n=183)[1]	Test Stat	P-Value[2]
Product Innovators (number)[3,4]	63 (84%)	52 (80%)	32 (74%)	147 (80%)	Pearson Chi-Square= 1.595, d.f.=2	P=0.451
Innovation Success (percent)[5,6]	27.3 (28.68)	49.8 (42.05)	18.8 (23.03)	33.4 (35.19)	$F_{(2,144)}$stat= 10.581	P=0.000

Source: Author's Survey

Notes:

1. The total number of respondents is 183 as one respondent answered anonymously, so it is not possible to identify the sector to which this respondent belongs.
2. Two-tailed test of significance.
3. The number of businesses that indicated they had introduced at least one new product/service in the three years between 2001 and 2003.
4. Percentage of respondents in each sector is in parentheses.
5. The percentage of 2003 sales attributed to products introduced in the previous three years. This variable only applies to product innovators.
6. Standard deviations are in parentheses.

Table 5.8 shows that the proportion of product innovators is consistent across sectors. The Pearson's Chi-Square probability is greater than 0.025 ($p>0.025$) which means that the null hypothesis of equality in the percentage of product innovators across sectors could not be rejected at a 95% confidence level. This indicates that there is no statistical evidence that a business' sector affects its likelihood of introducing a new product or service.

While there is no evidence of a difference in the incidence of product innovation across sectors, Table 5.8 indicates there is a difference across sectors in the proportion of turnover generated by new products. The null hypothesis of equal variance in mean turnover from new products across sectors can be rejected, as the F-statistic probability value is less than 0.025 ($p<0.025$). Businesses in the *ICT* sector earn a significantly greater proportion of turnover (49.8%) from newly introduced products.

It is reported in Table 5.4 that businesses in the *ICT* sector are younger, which may explain the greater percentage of turnover in these businesses that is attributable to newly introduced products.

Table 5.9 presents the incidence of product innovation and innovation performance by indigenous and foreign ownership. A test of the null hypothesis of equality in the percentage of product innovators in Irish and foreign-owned businesses cannot be rejected ($p>0.025$), meaning that there is no statistical evidence of a difference in the rate of product innovation between the two categories of business. Similarly, the independent t-test suggests there is no evidence of a variation in the proportion of turnover attributable to new products in Irish and foreign-owned businesses ($p>0.025$).

Table 5.9 – Product Innovation by Indigenous or Foreign Ownership					
	Ownership				
Variable	**Indigenous (n=98)**	**Foreign-Owned (n=86)**	**Total (n=184)**	**Test Statistic**	**P-Value[1]**
Product Innovators (number)[2,3]	83 (85%)	64 (74%)	147 (80%)	Pearson Chi-Square= 3.010, d.f.=1	P=0.083
Innovation Success (percent)[4,5]	38.0 (36.36)	27.4 (32.93)	33.4 (35.19)	$t_{(141)}$stat=1.848[6]	P=0.067

Source: Author's Survey

Notes:
1. This is a two-tailed test of significance.
2. The number of businesses that indicated they had introduced at least one new product/service in the three years between 2001 and 2003.
3. Percentage of respondents in each sector is in parentheses.
4. The percentage of 2003 sales attributed to products introduced in the previous three years. This variable only applies to product innovators.
5. Standard deviations are in parentheses.

Table 5.10 presents the number of product innovators and the innovation performance of businesses by age category. Business age has been included in estimations of sources of innovation in businesses by Roper (2001), Freel (2003) and Gordon and McCann (2005).

Table 5.10 – Product Innovation by Business Age							
	Age						
Variable	**0-5 years (n=49)**	**6-15 years (n=52)**	**16-25 years (n=40)**	**>25 years (n=43)**	**Total (n=184)**	**Test Statistic**	**P-Value[1]**
Product Innovators (number)[2,3]	39 (80%)	42 (81%)	32 (80%)	34 (79%)	147 (80%)	Pearson Chi-Square=0.046, d.f.=3	P=0.997
Innovation Success (percent)[4,5]	71.2 (35.69)	25.0 (28.27)	17.0 (19.68)	15.7 (17.04)	33.4 (35.19)	$F_{(3,143)}$stat= 36.194	P=0.000

Source: Author's Survey

Notes:
1. This is a two-tailed test of significance.
2. The number of businesses that indicated they had introduced at least one new product/service in the three years between 2001 and 2003.
3. Percentage of respondents in each sector is in parentheses.
4. The percentage of 2003 sales attributed to products introduced in the previous three years. This variable only applies to product innovators.
5. Standard deviations are in parentheses.

There is no evidence from the Chi-Square test of divergence across age groups in the proportion of product innovators ($p>0.025$). However, the F-statistic probability is less than 0.025 ($p<0.025$) which means that the null hypothesis of equal variance in mean turnover from new products across sectors can be rejected, indicating that younger businesses tend to have a greater proportion of turnover attributable to newly introduced products. For businesses less than 5 years old, the proportion of turnover in 2003 attributed to products or services introduced in the previous three years is 71.2%. The corresponding figure is smaller for each higher age group, reaching 15.7% for businesses older than 25 years.

Table 5.11 shows the number of product innovators and the average percentage of turnover attributable to new products and services categorized by business size. Schumpeter has been credited with the hypothesis that larger businesses are more innovative than smaller ones (1942:105-106). Scherer also argues that R&D may benefit from scale economies in other parts of a large business' operations (1980:414). Empirical evidence is divided on the effect on innovation of business size.

Table 5.11 – Product Innovation by Business Size[1]							
	Size						
Variable	Micro <10 employees (n=24)	Small 10-49 employees (n=77)	Medium 50-249 employees (n=63)	Large >250 employees (n=20)	Total (n=184)	Test Statistic	P-Value[2]
Product Innovators (number)[3,4]	21 (88%)	63 (82%)	48 (76%)	15 (75%)	147 (80%)	Pearson Chi-Square =1.87, d.f.=3	P=0.598
Innovation Performance (percent)[4,5]	72.9 (35.58)	29.8 (33.29)	26.5 (30.25)	15.3 (14.61)	33.4 (35.19)	$F_{(3,143)}$stat =13.896	P=0.000

Source: Author's Survey

Notes:
1. Categories of business size are based on the classification of small and medium-sized enterprises used by the European Union (European Commission, 2003c).
2. This is a two-tailed test of significance.
3. The number of businesses that indicated they had introduced at least one new product/service in the three years between 2001 and 2003.
4. Percentage of respondents in each sector is in parentheses.
5. The percentage of 2003 sales attributed to products introduced in the previous three years. This variable only applies to product innovators.
6. Standard deviations are in parentheses.

The Pearson Chi-Square test that there is no relationship between the number of product innovators and business age could not be rejected (p>0.025). However, the F-statistic probability is less than 0.025 so the null hypothesis of equal variance in mean turnover from new products across categories of business size can be rejected. Micro-sized businesses report that, on average, almost 73% of turnover in 2003 is generated by products or services introduced in the previous three years. This declines for each subsequent size category, and for large businesses the proportion is just over 15%. The one way ANOVA test suggests that this difference is statistically significant.

In total, 80% of businesses in the sample surveyed are product innovators. This level of product innovation activity compares favourably with other studies. Breathnach (1996) found that 62% of high- and medium to high-technology Irish manufacturing and internationally-traded services companies developed or introduced "technologically changed" products between 1993 and 1995. The categorisation of high and medium technology companies used in Breathnach (1996) is similar to those used in this study. Becker and Dietz (2004) find that 75.5% of German manufacturing businesses "realised product innovations" in the three years from 1990 to 1992. Forfás (2005) estimated that 74% of Irish businesses introduced new products in the three years between 2001 and 2004. These studies all adopted a broad definition of innovation, and since this study is also based on 'high-technology' sectors a relatively high level of product innovation is not surprising. While this study is not concerned primarily with the level of innovation output in Irish high-technology businesses, but rather with the sources of this innovation, the finding that a large proportion of these businesses consider themselves product innovators is notable and the policy implications are discussed in detail in section 5.7 later in this Chapter.

5.2.2 Process Innovation

Respondents are asked to indicate the extent to which their business introduced new processes between 2001 and 2003. The response indicates firstly whether the business is a process innovator or not. A process innovator is a business that has introduced any new processes in the three-year period from 2001 to 2003. Almost all respondents (98%) indicated that they have introduced new processes at least rarely in the three-year period. This is not surprising given the broad definition of process innovation used. The question also measures the frequency with which the business engages in process innovation. 43% of respondents indicate that they introduced new processes on a frequent or continuous basis. Table 5.12 presents the frequency of process innovation by sector.

Table 5.12 - Frequency of Process Innovation by Major Sector: number of respondents (percentages in parentheses[1])

	Sector			
	Chemicals/ Pharm.	**ICT**	**Electronic Devices**	**Total**
Never	1 (2%)	1 (2%)	2 (3%)	4 (2%)
Rarely	11 (26%)	15 (23%)	16 (21%)	42 (23%)
Regularly	17 (40%)	19 (30%)	22 (29%)	58 (32%)
Frequently	6 (14%)	10 (15%)	10 (13%)	26 (14%)
Continuously	8 (19%)	20 (31%)	25 (33%)	53 (29%)
Total	**43**	**65**	**75**	**183[2]**

Source: Author's Survey

Notes:
1. Due to rounding, percentages may not add to 100%.
2. The total number of respondents is 183 as one respondent answered anonymously, so it is not possible to identify the sector to which this respondent belongs.

A test of equality in the frequency of process innovation across sectors could not be rejected [Pearson's Chi-square =3.780, df=8, p-value = 0.876(2-tailed)]. This suggests that there is no evidence of variation in rates of process innovation across sectors.

Tables 5.13 to 5.15 present the proportion of businesses that are Regular Process Innovators by the same categories used for reporting product innovation, that is nationality of ownership, age and employment. For the purposes of these tables, ‘Regular Process Innovators’ include those that introduced new processes on a regular, frequent or continuous basis.

Table 5.13 shows the number of indigenous and foreign-owned businesses that are Regular Process Innovators. In this table the test of equality in the proportion of Regular Process Innovators in each ownership type cannot be rejected (p>0.025), which means there is no evidence that indigenous and foreign-owned businesses differ in the frequency of process innovation.

Table 5.13 – Regular Process Innovation by Indigenous or Foreign Ownership: number of respondents (percentages in parentheses)

	Ownership				
Variable	**Indigenous (n=98)**	**Foreign-Owned (n=86)**	**Total (n=184)**	**Test Statistic**	**P-Value[1]**
Regular Process Innovators[2]	72 (73%)	66 (77%)	138 (75%)	$t_{(181)}$stat= -0.511	P=0.610

Source: Author's Survey

Notes:
1. This is a two-tailed test of significance.
2. The number of respondents that indicated they introduced new processes on a regular, frequent or continuous basis in the years to the end of 2003.

Table 5.14 shows the proportion of regular process innovators by business age. There is no statistical evidence of a difference in the proportion of businesses in each age category that are Regular Process Innovators. The F-statistic probability value is not significant (p>0.025) so the null hypothesis of equality in the proportion of Regular Process Innovators in each group cannot be rejected.

Table 5.14 – Regular Process Innovation by Business Age: number of respondents (percentages in parentheses)

Variable	Age 0-5 years (n=49)	6-15 years (n=52)	16-25 years (n=40)	>25 years (n=43)	Total (n=184)	Test Statistic	P-Value[1]
Regular Process Innovators[2]	39 (80%)	40 (77%)	31 (78%)	28 (65%)	138 (75%)	$F_{(3,180)}$stat= 1.004	P=0.393

Source: Author's Survey

Notes:
1. This is a two-tailed test of significance.
2. The number of respondents that indicated they introduced new processes on a regular, frequent or continuous basis in the years to the end of 2003.

Table 5.15 shows the proportion of regular process innovators by business size. In this table there is no evidence of difference in the frequency of process innovation across business sizes. Tests of equality of proportions across size groups could not be rejected (p>0.025).

Table 5.15 – Regular Process Innovation by Business Size: number of respondents (percentages in parentheses)

Variable	Size[1] Micro <10 employees (n=24)	Small 10-49 employees (n=77)	Medium 50-249 employees (n=63)	Large >250 employees (n=20)	Total (n=184)	Test Statistic	P-Value[2]
Regular Process Innovators[3]	18 (75%)	56 (73%)	46 (73%)	18 (90%)	138 (75%)	$F_{(3,180)}$stat =0.908	P=0.438

Source: Author's Survey

Notes:
1. Categories of business size are based on the classification of small and medium-sized enterprises used by the European Commission (2003c).
2. This is a two-tailed test of significance.
3. The number of respondents that indicated they introduced new processes on a regular, frequent or continuous basis in the years to the end of 2003.

The rate of product and process innovation for businesses engaged in research and development and interaction for innovation is set out later in this Chapter. However, the next section first presents the extent of research and development activity and the incidence and frequency of interaction for innovation.

5.3. Research and Development Effort

The third section of the questionnaire focuses on the sources of product and process innovation. The first series of questions in this section of the questionnaire relate to the business' R&D effort. Respondents are asked in Question C.1 whether their business performed R&D between 2001 and 2003. If a respondent indicated that their business did undertake R&D, they are asked to indicate whether their business had a dedicated R&D department.

Table 5.16 shows the incidence of R&D and the number of businesses with dedicated R&D departments by sector. In total, 122 (67%) respondents indicated that they undertook R&D between 2001 and 2003. Of those businesses, 75 (62%) had a dedicated R&D department during those three years. There is no evidence of a difference in the proportion of businesses in each sector performing R&D nor in the proportions using a dedicated R&D department ($p>0.025$ for both).

Table 5.16 – R&D Activity by Sector: number of respondents (percentages in parentheses)						
	Sector					
Variable	Elec. Devices (n=75)	ICT (n=65)	Chem./ Pharm. (n=43)	Total (n=183)[1]	Test Stat	P-Value[2]
Perform R&D[3]	49 (65%)	48 (74%)	25 (58%)	122 (67%)	Pearson Chi-Square=2.975, d.f.=2	P=0.226
R&D Dept.[4]	28 (57%)	30 (63%)	17 (68%)	75 (62%)	Pearson Chi-Square= 0.859, d.f.=2	P=0.651

Source: Author's Survey

Notes:

1. The total number of respondents is 183 as one respondent answered anonymously, so it is not possible to identify the sector to which this respondent belongs.
2. This is a two-tailed test of significance.
3. The number of businesses that performed R&D in the three years from 2001 to 2003.
4. The number of businesses that performed R&D that had a dedicated R&D department.

Table 5.17 shows the number and percentage of indigenous and foreign-owned businesses that performed R&D and the number and percentage that did so in a dedicated R&D department.

Table 5.17 – R&D Activity by Ownership: number of respondents (percentages in parentheses)					
	Ownership				
Variable	Indigenous (n=98)	Foreign-Owned (n=86)	Total (n=184)	Test Statistic	P-Value[1]
Perform R&D[2]	78 (80%)	45 (52%)	123 (67%)	$t_{(182)}$stat= 4.072	P=0.000
R&D Dept.[3]	43 (55%)	33 (73%)	76 (62%)	$t_{(121)}$stat= -2.018	P=0.046

Source: Author's Survey

Notes:

1. This is a two-tailed test of significance.
2. The number of businesses that performed R&D in the three years from 2001 to 2003.
3. The number of businesses that performed R&D that had a dedicated R&D department.

A significantly greater proportion of indigenous businesses in the high-technology sectors perform R&D ($p<0.025$). Table 5.17 shows that 78 (80%) indigenous businesses performed R&D compared to 45 (52%) foreign-owned businesses. Among businesses that do perform R&D, a greater proportion (73%) of foreign-owned businesses have a dedicated R&D department, suggesting that R&D activity may be more take a more formal structure in these businesses. This finding is significant at a 90% confidence level ($p<0.05$).

Table 5.18 presents R&D activity by business age categories.

Table 5.18 – R&D Activity by Business Age: number of respondents (percentages in parentheses)

	Age						
Variable	**0-5 years (n=49)**	**6-15 years (n=52)**	**16-25 years (n=40)**	**>25 years (n=43)**	**Total (n=184)**	**Test Statistic**	**P-Value[1]**
Perform R&D[2]	38 (78%)	38 (73%)	25 (63%)	22 (51%)	123 (80%)	Pearson Chi-Square=8.558, d.f.=3	P=0.036
R&D Dept[3]	28 (74%)	22 (58%)	13 (52%)	13 (59%)	76 (72%)	Pearson Chi-Square=3.604, d.f.=3	P=0.308

Source: Author's Survey

Notes:
1. This is a two-tailed test of significance.
2. The number of businesses that performed R&D in the three years from 2001 to 2003.
3. The number of businesses that performed R&D that had a dedicated R&D department.

Table 5.18 shows that younger businesses have a higher incidence of R&D than older businesses. In businesses that are less than five years old, 78% perform R&D, while 51% of businesses aged over 25 years performed R&D. This is a statistically significant difference at a 90% confidence level ($p<0.05$). However, there is no statistical evidence of a variation across age groups in the proportion of businesses performing R&D in dedicated departments (p>0.025).

Table 5.19 shows the incidence of R&D and dedicated R&D departments across business size categories.

Table 5.19 – R&D Activity by Business Size: number of respondents (percentages in parentheses)

	Size						
Variable	**Micro <10 employees (n=24)**	**Small 10-49 employees (n=77)**	**Medium 50-249 employees (n=63)**	**Large 250+ employees (n=20)**	**Total (n=184)**	**Test Statistic**	**P-Value[1]**
Perform R&D[2]	19 (79%)	54 (70%)	37 (59%)	13 (65%)	123 (67%)	Pearson Chi-Square=3.922, d.f.=3	P=0.270
R&D Dept[3]	10 (53%)	29 (54%)	27 (73%)	10 (77%)	76 (62%)	Pearson Chi-Square=5.391, d.f.=3	P=0.145

Source: Author's Survey

Notes:
1. This is a two-tailed test of significance.
2. The number of businesses that performed R&D in the three years from 2001 to 2003.
3. The number of businesses that performed R&D that had a dedicated R&D department.

A higher percentage of smaller businesses report that they performed R&D, though there is no statistical evidence of a difference across size bands (p>0.025). Also, the null hypothesis of equality in the number of businesses in each size band that had a dedicated R&D department cannot be rejected (p>0.025).

The survey questionnaire probed the extent of R&D activity in more detail by asking, for the three years from 2001 to 2003, the average number of employees in R&D departments, the proportion of turnover invested in R&D and the extent of financial support for R&D as a percentage of total R&D expenditure that respondents received from innovation-supporting agencies.

Table 5.20 presents these R&D input indicators by sector, ownership, business age and business size.

Table 5.20 – R&D Input Indicators by Sector, Ownership, Age and Size

	R&D Employment[1] (Mean)[4]	***R&D Spend[2] (Mode)[5]***	***R&D Support[3] (Mode)[5]***
Sector			
Chemicals and Pharmaceuticals	12.5 (19.3)	0 to 5% (45%)	Zero
ICT	11.9 (11.3)	More than 25% (66%)	Zero
Electronic Devices and Engineering	8.7 (17.7)	0 to 5% (25%)	Zero
Ownership			
Indigenous	10 (15.2)	0 to 5% (70%)	Zero
Foreign-Owned	13 (16.9)	0 to 5% (39%)	Zero
Business Age			
<5 Years	14.8 (20.2)	More than 25% (47%)	Zero
6-15 Years	12.5 (19.6)	6% to 10% (66%)	Zero
16-25 Years	8.3 (8.2)	0 to 5% (39%)	Zero
>25 Years	8.4 (5.8)	0 to 5% (13%)	Zero

Table 5.20 continued – R&D Input Indicators by Sector, Ownership, Age and Size	R&D Employment[1] (Mean)[4]	R&D Spend[2] (Mode)[5]	R&D Support[3] (Mode)[5]
Business Size			
Micro (<10 employees)	2.1 (1.5)	More than 25% (50%)	Zero
Small (<50 employees)	7.7 (9.3)	0 to 5% (68%)	Zero
Medium(<250 employees)	15.0 (19.6)	0 to 5% (38%)	Zero
Large (>250 employees)	16.4 (24.7)	0 to 5% (38%)	Zero
Total	11.0 (15.7)	0 to 5% (57%)	Zero

Source: Author's Survey

Notes:

1. Average number of full-time employees in R&D between 2001 and 2003.
2. R&D expenditure as a proportion of business turnover between 2001 and 2003, using an interval measure.
3. Financial support from innovation-supporting agencies as a proportion of total R&D expenditure between 2001 and 2003, using an interval measure.
4. The numbers in parentheses are standard deviation.
5. The percentages in parentheses are the proportion of respondents not in the modal category.

The only significant difference in R&D employment levels in Table 5.20 is between business size bands. At a 90% level of confidence ($p<0.05$), larger businesses appear to have higher average R&D employment levels [$F_{(3,72)}$stat=2.898, p=0.041].

5.3.1 R&D and Innovation Output

Turning to the relationship between R&D activity and innovation output, Table 5.21 presents the incidence of R&D in product innovators. Product innovators are businesses that have introduced at least one new product in the three years between 2001 and 2003.

Table 5.21 - R&D Activity by Product Innovators: Number and Percentage of Respondents				
	Perform R&D		**R&D Department**	
	Frequency	*Percent* [1]	*Frequency*	*Percent* [2]
Innovators	110	75%	70	64%
Non-Innovators	13	35%	6	46%
	123	**67%**	**76**	**62%**

Source: Author's Survey

Notes:
1. This is the percentage of innovators/non-innovators that undertook R&D in the three years between 2001 and 2003.
2. This is the percentage of innovators/non-innovators that performed R&D and had a dedicated R&D department.

There is a significant difference between the percentages of product innovators and non-innovators that perform R&D. Table 5.21 shows 110 (75%) product innovators performed R&D, while 13 (36%) non-innovators performed R&D [$t_{(141)}$stat=1.848, p=0.000]. While 70 (64%) product innovators and 6 (46%) non-innovators had a dedicated R&D department, an independent t-test for equality of means cannot be rejected [$t_{(121)}$stat=-1.224, p=0.223].

Table 5.22 presents R&D activity by Regular and Irregular Process Innovators. This categorisation is necessary because 98% of respondents indicated they had introduced new processes at least rarely in the reference period. Regular Process Innovators are businesses that indicated that they introduced new processes on at least a regular basis. This includes those businesses that introduced new processes on a regular, frequent or continuous basis. Irregular Process Innovators are those businesses that never or rarely introduce process innovations. It is appropriate to categorise the data in this way as there is a distinct difference between those that rarely and regularly introduce process innovation.

Table 5.22 – R&D Activity by Process Innovators: Number and Percentage of Respondents				
	Perform R&D		**R&D Function**	
	Frequency	*Percent*[1]	*Frequency*	*Percent*[2]
Regular Innovators	104	75%	63	61%
Irregular Innovators	19	41%	13	68%
	123	68%	76	62%

Source: Author's Survey

Notes:
1. This is the percentage of process innovators/non-innovators that undertook R&D in the three years between 2001 and 2003.
2. This is the percentage of innovators/non-innovators that performed R&D and had a dedicated R&D department.

Similarly to the findings in relation to product innovation, Regular Process Innovators appear significantly more likely to perform R&D [$t_{(182)}$stat=-4.450, p=0.000]. Table 5.22 shows that 104 (75%) Regular Process Innovators performed R&D compared to 19 (41%) Irregular Process Innovators. There is no statistical evidence of a difference in the percentage of Regular Process Innovators that have a dedicated R&D compared to Irregular Process Innovators [$t_{(121)}$stat=0.655, p=0.518].

The relationships between R&D and product and process innovation rates are analysed in more detail in Chapters 6 and 7.

5.4. Interaction for Product Innovation

It has been seen previously in Table 5.8 that 147 (80%) businesses indicated that they have introduced new products to the market between 2001 and 2003. In Table 5.21 it is noted that, of those businesses, 110 (75%) indicated that they performed R&D in the same period. In relation to process innovation it has been shown in Table 5.12 that 138 (75%) businesses introduced new processes on at least a regular basis between 2001 and 2003. Table 5.22 shows that, of these businesses, 104 (75%) indicated that they undertook R&D in the same period.

These figures suggest that there are businesses that have not undertaken R&D, but have introduced product and/or process innovations. A potential source of knowledge for these innovations may be the business' interaction with a range of other companies or supporting institutions. Of course, those businesses that have performed R&D may also benefit from interaction for innovation. In fact, performing R&D may enhance the benefit of interaction for innovation; Cohen and Levinthal (1990) contend that businesses performing R&D build up absorptive capacity that enables them to identify and exploit external knowledge.

The remaining questions in Section C of the survey addresses interaction for innovation with six interaction agents, which comprise other businesses, such as other group companies, suppliers, customers and competitors, academic-based researchers and innovation supporting agencies.

The first question in relation to interaction, Question C.7, refers to membership of a business association or lobby group. Table 5.23 presents business association membership by sector.

Table 5.23 - Business Association Membership by Sector (number of respondents and percentage in each sector)		
	n	***%***
Chemicals and Pharmaceuticals	35	81%
ICT	42	64%
Electronic Devices and Engineering	47	64%
Total	***124***	***68%***

Source: Author's survey

In total, 124 (68%) businesses are members of a business association. The null hypothesis of equality across sectors in the percentage of businesses that are members of a business association proportions across sectors cannot be rejected [Pearson's Chi-square = 4.844, df = 2, p-value = 0.089].

Subsequent questions examine more specifically the nature of interaction for innovation. Question C.8 asked respondents to indicate the frequency of interaction with six interaction agents in relation to product innovation between 2001 and 2003. Frequency of interaction is measured on a scale from continuously, to frequently, regularly, rarely and never.

Table 5.24 presents the incidence of interaction with each interaction agent in relation to product innovation by sector. This shows the number of businesses that indicated that they interacted at any frequency level with each interaction agent.

Table 5.24 - Incidence of Interaction for Product Innovation by Sector: number of respondents (percentages in parentheses)						
	Sector					
Interaction Agent	**Elec Devices (n=75)**	**ICT (n=65)**	**Chem/ Pharm (n=43)**	**Total (n=183)[1]**	**Test Stat**	**P-Value[2]**
Group	32 (94%)	30 (86%)	32 (100%)	94 (93%)	Pearson Chi-Square=5.376, d.f.=2	P=0.068
Suppliers	70 (93%)	49 (75%)	41 (95%)	160 (87%)	Pearson Chi-Square=13.415, d.f.=2	P=0.001
Customers	70 (95%)	58 (91%)	41 (95%)	169 (93%)	Pearson Chi-Square=1.230, d.f.=2	P=0.541
Competitors	45 (62%)	38 (59%)	24 (56%)	107 (59%)	Pearson Chi-Square=0.399, d.f.=2	P=0.819
Academic	49 (67%)	30 (47%)	29 (67%)	108 (60%)	Pearson Chi-Square=7.129, d.f.=2	P=0.028
IS Agencies	50 (68%)	42 (66%)	30 (70%)	122 (67%)	Pearson Chi-Square=0.202, d.f.=2	P=0.904

Source: Author's survey

Notes
1. The total number of respondents is 183 as one respondent answered anonymously, so it is not possible to identify the sector to which this respondent belongs.
2. This is a two-tailed test of significance.

Table 5.24 shows that for businesses belonging to a group of companies, there is a high incidence of interaction with other group companies in relation to product innovation across all sectors. In fact 100% of businesses in the *Chemicals and Pharmaceuticals* sector interacted with other group companies. There is no evidence of a variation in the incidence of interaction with group companies by sector (p>0.025).

Interaction with suppliers is high, particularly in the *Electronic Devices and Engineering* and *Chemicals and Pharmaceutical* sectors where 93% and 95% respectively of businesses indicate that they have interacted with suppliers. The *ICT* sector has a lower incidence of interaction with suppliers at 75% and this difference is significant ($p<0.025$). There are no significant differences across sectors for customers, competitors and innovation-supporting agencies.

The only other interaction agent for which there is a significant variation across sectors is academic-based researchers, which is very close to being significant at a 95% confidence level ($p=0.026$). This suggests that businesses in the *ICT* sector (at 47%) tend to have lower incidence of interaction with academic-based researchers than other sectors.

A striking pattern that emerges from Table 5.24 is the apparent difference in the incidence of interaction for product innovation between the first three interaction agents, group companies, suppliers and customers, and the other three agents, competitors, academic-based researchers and innovation-supporting agencies. An examination of the results in Table 5.24 shows that the percentage of businesses in each sector that interact with the first three agents is above 90% in seven out of nine cases, and does not fall below 75%. In contrast, for the second three agents, the percentage of businesses that interact for product innovation does not rise above 70%. This pattern is considered again later in this Chapter.

Table 5.25 presents the incidence of interaction for product innovation by ownership.

Table 5.25 - Incidence of Interaction for Product Innovation by Ownership: number of respondents (percentages in parentheses)					
	Ownership				
Interaction Agent	**Indigenous**	**Foreign**	**Total**	**Test Statistic**	**P-Value[1]**
Group	14 (74%)	80 (98%)	94 (93%)	Pearson Chi-Square=13.634,d.f.=1	P=0.000
Suppliers	86 (88%)	75 (87%)	161 (88%)	Pearson Chi-Square=0.012,d.f.=1	P=0.911
Customers	93 (95%)	77 (92%)	170 (93%)	Pearson Chi-Square=0.767,d.f.=1	P=0.381
Competitors	65 (66%)	42 (50%)	107 (59%)	Pearson Chi-Square=4.976,d.f.=1	P=0.026
Academic	57 (58%)	51 (61%)	108 (60%)	Pearson Chi-Square=0.201,d.f.=1	P=0.654
Agencies	72 (74%)	51 (61%)	123 (68%)	Pearson Chi-Square=3.359,d.f.=1	P=0.067

Source: Author's survey

Notes
1. This is a two-tailed test of significance.

Table 5.25 suggests that there is no evidence of divergence in the incidence of interaction for indigenous and foreign-owned businesses across most interaction agents. The exceptions (p>0.025) are for other group companies, with which foreign-owned businesses are more likely to interact (98% of foreign-owned businesses compared to 74% of indigenous businesses), and competitors, with which, at 66%, there is a higher incidence among indigenous businesses. A more detailed breakdown of the results in Tables 5.24 and 5.25 is presented in Appendix 3. This Appendix presents the frequency of interaction for product innovation, by sector and ownership, for each interaction agent.

The pattern referred to in Table 5.24 is evident also in Table 5.25. The incidence of interaction for product innovation is generally higher with group companies, suppliers and customers than it is with competitors, academic-based researchers and innovation-supporting agencies. The significance of this gap between the groups of interaction agents is tested for the frequency of interaction, which is presented in the following six tables.

The pattern referred to previously can be seen more clearly in Table 5.26. This table shows the frequency of interaction by agent. The frequency intervals are consolidated into two groups. The first contains those respondents that indicated that they never or rarely interacted with each interaction agent. The second group contains those that indicated they interacted on a regular, frequent or continuous basis with each interaction agent.

Table 5.26 – Frequency of Interaction for Product Innovation by Interaction Agent (number of respondents)

	Agent					
	Group	Supplier	Customer	Competitor	Academic	Agency
Never/Rarely	11 (11%)	33 (17%)	18 (9%)	125 (68%)	122 (67%)	102 (56%)
Regularly to Continuously	91 (89%)	151 (82%)	164 (90%)	57 (31%)	59 (33%)	80 (44%)
Total	102	184	182	182	181	182

Source: Author's survey

A chi-square test of the null hypothesis that the frequency of interaction is not related to the interaction agent is rejected [Pearson’s Chi-square = 279.456, df=5, p-value =

0.000]. This indicates there are differences in the frequency of interaction across agents. There is an obvious difference in the frequencies observed in Table 5.26 (and in previous tables) between the first three interaction agents and the second three interaction agents. These agents are consolidated and the frequency of interaction with these groups of agents is shown in Table 5.27.

Table 5.27 – Frequency of Interaction by Grouped Interaction Agent: number of respondents (percentages in parentheses)

	Group/ Supplier/ Customer	Competitor/ Academic/ Agency
Never/Rarely	62 (13%)	349 (64%)
Regularly to Continuously	406 (87%)	196 (36%)
Total	468	545

Source: Author's survey

There is a statistically significant difference in the frequency of interaction for product innovation with the first group of agents compared to the second group [Pearson's Chi-square = 269.37, df=1, p-value = 0.000].

The conclusion that can be drawn from this analysis is that interaction for product innovation with group companies, suppliers and customers is strong relative to interaction with competitors, academic-based researchers and innovation-supporting agencies. Strong interaction with the first group is consistent with the Kline and Rosenberg model of a market-led innovation model (1986). Saxenian (1996) contends that the success of Silicon Valley in promoting innovative businesses is based on interaction between small businesses that shared knowledge, even with competitors, and close links between businesses and university researchers. These results suggest that these are relatively unimportant sources of knowledge for Irish high-technology businesses. The relatively weak interaction with academic-based researchers and innovation-supporting agencies may also have implications for the success of state investment in basic research and building business networks. This is considered in greater detail in the final section of this Chapter.

A more detailed analysis of the frequency of interaction for product innovation with each agent by sector and nationality of ownership is contained in Appendix 3. This analysis shows that there is a greater frequency of interaction with other group companies among foreign-owned businesses and that businesses in the *Chemicals and Pharmaceuticals* sector have a higher frequency of interaction with suppliers for product innovation than the other two sectors. There is no evidence of a difference in the frequency of interaction with each agent by sector or nationality of ownership.

5.4.1 The Relationship between Product Innovation and Interaction

The relationship between R&D and product innovation is presented earlier in Table 5.21. Interaction is also considered a source of innovation. Table 5.28 presents a series of bivariate correlations between whether a business is a product innovator and the frequency of interaction for product innovation with each agent.

Table 5.28 – Correlation between Product Innovation[1] and Frequency of Interaction by Agent

	N	Coefficient
Group Companies	102	0.068
Supplier	184	0.219[2]
Customer	182	0.381[2]
Competitor	182	0.880
Academic-based researchers	181	0.660
Innovation-supporting agencies	182	0.228[2]

Source: Author's survey

Notes:
1. Product innovation is a binary variable taking a value of 1 if a business has introduced a new product or service in the three years from 2001 and 2003
2. Correlation is significant at the 0.01 level (2-tailed)

A positive relationship exists between innovation and frequency of interaction for each interaction agent, though this is significant for only three, suppliers, customers and innovation-supporting agencies. This positive relationship is analysed in more detail in subsequent Chapters, when the product innovation output is controlled for business characteristics, R&D and interaction. This sheds light on the extent to which R&D and interaction may be complements or substitutes.

5.4.2 Proximity for Interaction for Product Innovation

Analysing the frequency of interaction for innovation raises the issue of geographical proximity and whether businesses are more likely to interact with those businesses and institutions that are closer to them. Respondents indicated the average one-way driving-time between their business and the single most important interaction agent. Driving times are categorised into five intervals, less than half and hour, half to one hour, one to two hours, two to four hours and greater than four hours.

Table 5.29 shows the proximity of interaction agents for product innovation. For ease of analysis, in this table average one-way driving times are grouped into three categories.

Table 5.29 – Proximity for Product Innovation by Interaction Agent: number of respondents (percentages in parentheses)						
	Agent					
	Group	Supplier	Customer	Competitor	Academic	Agency
<1 hour	7 (8%)	28 (20%)	23 (15%)	18 (20%)	35 (39%)	50 (49%)
1 to 4 hours	2 (2%)	33 (24%)	41 (27%)	16 (18%)	30 (33%)	41 (40%)
>4 hours	76 (89%)	78 (56%)	89 (58%)	55 (62%)	25 (28%)	11 (11%)
Total	85 (100%)	139 (100%)	153 (100%)	89 (100%)	90 (100%)	102 (100%)

Source: Author's survey

A pattern emerges from Table 5.29 that group companies, suppliers, customers and competitors with which businesses interact for product innovation tend to be located at a greater distance than academic-based researchers and innovation-supporting agencies with which businesses interact. The null hypotheses of equal proximity across all agents is rejected [Pearson’s Chi-square =151.96, df=10, p-value = 0.000].

It has already been noted that the first three interaction agents are the most important for product innovation. It is striking then that this interaction tends occur over long distances and that these interaction agents are not geographically proximate. This finding has implications for Irish policy makers, which is drawn out in the final section of this Chapter.

Appendix 4 contains an analysis of the proximity of interaction agents by sector and nationality of ownership. This shows that there are significant differences across sectors in relation to the proximity to suppliers and innovation-supporting agencies. Businesses in the *Chemicals and Pharmaceuticals* sector appear to interact with suppliers over greater distances than the other two sectors. Businesses in the *ICT* sector are more likely to interact with innovation-supporting agencies located less than one hours' drive away. There are no other significant differences between sectors. Appendix 4 also shows that foreign-owned businesses are more likely than indigenous businesses to interact over greater distances with other group companies, though this is hardly surprising since foreign-owned businesses are likely to interact for innovation with parent or other group companies abroad. Indigenous businesses are more likely to interact over shorter distances with innovation supporting agencies. There are no other significant differences between indigenous and foreign-owned businesses.

5.5 Interaction for Process Innovation

In Questions C.10 and C.11, respondents are asked a similarly constructed set of questions in relation to the incidence and frequency of interaction for process innovation, and in relation to the geographic proximity of interaction agents. Table 5.30 shows the incidence of interaction for process innovation by sector.

Table 5.30 - Incidence of Interaction for Process Innovation by Sector: number of respondents (percentage in parentheses)						
	Sector					
Interaction Agent	**Elec Devices**	**ICT**	**Chem/ Pharm**	**Total[1]**	**Test Statistic**	**P-Value**
Group	31 (97%)	31 (94%)	31 (97%)	93 (96%)	Pearson Chi-Square=0.475 d.f.=2	P=0.789
Suppliers	63 (86%)	42 (67%)	42 (98%)	147 (82%)	Pearson Chi-Square=18.203, d.f.=2	P=0.000
Customers	57 (78%)	50 (83%)	34 (79%)	143 (80%)	Pearson Chi-Square=0.442 d.f.=2	P=0.802
Competitors	32 (44%)	25 (40%)	19 (44%)	76 (43%)	Pearson Chi-Square=0.363 d.f.=2	P=0.834
Academic	35 (49%)	21 (34%)	22 (51%)	78 (44%)	Pearson Chi-Square=4.097 d.f.=2	P=0.129
IS Agencies	41 (57%)	22 (36%)	25 (58%)	88 (50%)	Pearson Chi-Square=7.749 d.f.=2	P=0.021

Source: Author's survey

Notes:
1. This is a two-tailed test of significance.

A similar pattern emerges in Table 5.30 to that seen in relation to product innovation (Table 5.24), where the incidences of interaction are higher with group companies, suppliers and customers than with competitors, academic-based researchers and innovation-supporting agencies. However in this case, in a reverse of the product innovation results, the incidence of interaction with suppliers is higher than it is with customers. This seems plausible as process innovation may be stimulated by, for example, new equipment or new sources of materials from suppliers. New equipment may enable or require new processes to be adopted in a business. The suppliers of this equipment may provide training or suggestions on how best to utilize the new equipment. In this context, businesses may look to backward linkages to suppliers to identify new processes that increase productivity or reduce cost, while product innovation may require these businesses to look to forward linkages to customers to identify market opportunities for new products and services. This is investigated further in Chapters 6 and 7.

The only interaction agents for which there is evidence of a variation in the incidence of interaction for process innovation across sectors are suppliers and innovation-supporting agencies ($p<0.025$). While 86% of businesses in the *Electronic Devices and Engineering* sector and 98% of businesses in the *Chemicals and Pharmaceuticals* sector interacted with suppliers, only 68% of businesses in the *ICT* sector did so. Only 36% of *ICT* businesses interacted with innovation-supporting agencies compared to 57% of *Electronic Devices and Engineering* businesses and 58% of *Chemicals and Pharmaceuticals* businesses.

Table 5.31 shows the incidence of interaction for process innovation by indigenous and foreign-owned businesses.

Table 5.31 - Incidence of Interaction for Process Innovation by Ownership: number of respondents (percentage in parentheses)					
	Ownership				
Interaction Agent	**Indigenous**	**Foreign**	**Total**	**Test Statistic**	**P-Value[1]**
Group	16 (94%)	77 (96%)	93 (96%)	Pearson Chi-Square=0.161,d.f.=1	P=0.688
Suppliers	73 (76%)	75 (89%)	148 (82%)	Pearson Chi-Square=5.376,d.f.=1	P=0.020
Customers	76 (78%)	68 (82%)	144 (80%)	Pearson Chi-Square=0.358,d.f.=1	P=0.550
Competitors	46 (47%)	30 (37%)	76 (43%)	Pearson Chi-Square=2.136,d.f.=1	P=0.144
Academic	41 (42%)	37 (46%)	78 (44%)	Pearson Chi-Square=0.209,d.f.=1	P=0.648
IS Agencies	49 (51%)	40 (49%)	89 (50%)	Pearson Chi-Square=0.023,d.f.=1	P=0.880

Source: Author's survey

Notes:
1. This is a two-tailed test of significance.

There is no evidence of a difference between ownership types in the incidence of interaction for process innovation for five of the six interaction agents. The exception is suppliers, with which foreign businesses are significantly more likely to interact than indigenous businesses ($p<0.025$). While 76% of indigenous businesses interacted with suppliers, 89% of foreign businesses did so.

Table 5.31 also displays the distinct gap between the incidence of interaction with the first three interaction agents and the second three interaction agents. For both ownership types, the incidence of interaction with competitors, academic-based researchers and innovation-supporting agencies rarely reaches 50%. This compares with rates of 76% to 96% for interaction with group companies, suppliers and customers.

Table 5.32 presents the frequency of interaction with each interaction agent for process innovation. For exposition purposes the frequencies are divided into two groups showing the number and percentage of businesses that interact rarely or never and those that interact continuously, frequently and regularly with each interaction agent.

Table 5.32 – Frequency of Interaction for Process Innovation by Interaction Agent: number of respondents (percentages in parentheses)

	Agent					
	Group	Supplier	Customer	Competitor	Academic	Agency
Never/Rarely	14 (14%)	58 (32%)	52 (29%)	148 (83%)	141 (79%)	127 (71%)
Regularly to Continuously	85 (86%)	122 (68%)	128 (88%)	31 (17%)	37 (21%)	51 (29%)
Total	99	180	180	179	178	178

Source: Author's survey

There is a clear gap between the frequency of interaction with other group companies, suppliers and customers on the one hand and competitors, academic-based researchers and innovation-supporting agencies on the other hand. A chi-square test of the null hypothesis that the frequency of interaction is not related to the interaction agent is rejected [Pearson’s Chi-square = 270.033, df=5, p-value = 0.000]. This result is similar to that seen for interaction for product innovation. These agents are consolidated and the frequency of interaction with these groups of agents is shown in Table 5.33.

There is a statistically significant difference in the frequency of interaction for process innovation with the first group of agents compared to the second group [Pearson's Chi-square = 256.351, df=1, p-value = 0.000].

Table 5.33 – Frequency of Interaction by Grouped Interaction Agent: number of respondents (percentages in parentheses)

	Group/ Supplier/ Customer	Competitor/ Academic/ Agency
Never/Rarely	124 (13%)	416 (64%)
Regularly to Continuously	335 (87%)	119 (36%)
Total	459	535

The conclusion that can be drawn from this analysis is that, just as it is for product innovation, interaction for process innovation with group companies, suppliers and customers is strong relative to interaction with competitors, academic-based researchers and innovation-supporting agencies.

A more detailed analysis of the frequency of interaction for process innovation with each agent by sector and nationality of ownership is contained in Appendix 5. The only significant difference that emerges in this analysis is that the *ICT* sector displays a lower frequency of interaction with suppliers that other sectors.

5.5.1 The Relationship between Process Innovation and Interaction

The issue arises as to whether those businesses that exhibit more frequent levels of interaction for process innovation tend to introduce more new processes. Table 5.34 presents the incidence of interaction with each interaction agent for regular process innovators and irregular process innovators. In this table, regular process innovators are those respondents that indicated that they introduced new processes on a regular, frequent or continuous basis in the three years between 2001 and 2003. Irregular process innovators are those that indicated that they did not introduce any process innovations or did so rarely over the same period.

Table 5.34 - Incidence of Interaction for Process Innovation for Regular Process Innovators: number of respondents (percentages in parentheses)

Interaction Agent	Regular Innovator[1]	Irregular Innovator[2]	Total	Test Statistic	P-Value[3]
Group	73 (97%)	20 (91%)	93 (96%)	Pearson Chi-Square=1.776 d.f.=1	P=0.183
Suppliers	116 (87%)	32 (70%)	148 (82%)	Pearson Chi-Square=6.772 d.f.=1	P=0.009[4]
Customers	113 (84%)	31 (67%)	144 (80%)	Pearson Chi-Square=6.140 d.f.=1	P=0.013[5]
Competitors	60 (45%)	16 (36%)	76 (43%)	Pearson Chi-Square=1.172 d.f.=1	P=0.279
Academic	60 (46%)	18 (39%)	78 (44%)	Pearson Chi-Square=0.554 d.f.=1	P=0.457
IS Agencies	73 (55%)	16 (35%)	89 (50%)	Pearson Chi-Square=5.746 d.f.=1	P=0.017[6]

Source: Author's survey

Notes

1. Regular process innovators have introduced new processes on a regular, frequent or continuous basis in the three years from 2001 to 2003.
2. Irregular process innovators have never or rarely introduced new processes in the three years from 2001 to 2003.
3. This is a two-tailed test of significance.
4. Using Yates' correction for continuity the result is also significant at a 95% confidence level. Continuity Correction=5.659, d.f.=1, p=0.017.
5. Using Yates' correction for continuity the result is also significant a 95% confidence level. Continuity Correction=5.127, d.f.=1, p=0.024.
6. Using Yates' correction for continuity the result is also significant a 95% confidence level. Continuity Correction=4.954, d.f.=1, p=0.026

Table 5.34 shows that regular process innovators exhibit a higher incidence of interaction across all interaction agents. This divergence is most striking in relation to suppliers and customers; 116 (87%) regular innovators interacted with suppliers compared to 32 (68%) irregular innovators and 112 (85%) regular innovators interacted with customers compared to 31 (66%) irregular innovators.

Table 5.35 presents a series of bivariate correlations between the whether a business is a Regular Process Innovator and the frequency of interaction for process innovation with each agent.

A positive relationship exists between the frequency of process innovation and frequency of interaction with each interaction agent, though this is significant for only three, suppliers, customers and innovation-supporting agencies. These are the same three interaction agents that displayed a significant correlation with product innovation.

Table 5.35 – Correlation between Regular Process Innovation[1] and Frequency of Interaction by Agent

	N	Coefficient
Group Companies	99	0.123
Supplier	180	0.236[2]
Customer	180	0.280[2]
Competitor	179	0.087
Academic-based researchers	178	0.096
Innovation-supporting agencies	178	0.234[2]

Source: Author's survey

Notes:
1. A binary variable taking a value of 1 if a business has introduced new process on a regular, frequent or continuous basis in the three years from 2001 and 2003
2. Correlation is significant at the 0.01 level (2-tailed)

5.5.2 Proximity for Interaction for Process Innovation

Turning to the issue of geographical proximity and interaction for process innovation, A similar pattern emerges in relation to the proximity of interaction agents for process innovation to that seen in connection with product innovation (see Table 5.29) This can be seen in Table 5.36, which shows the proximity of interaction agents for process innovation by agent. For this table, average driving times are consolidated into three groups.

Table 5.36 – Proximity[1] of Interaction Agents for Interaction for Process Innovation: number of respondents (percentages in parentheses[2])						
	Agent					
	Group	Supplier	Customer	Competitor	Academic	Agency
<1 hour	6 (7%)	24 (18%)	24 (19%)	16 (22%)	34 (43%)	41 (46%)
1 to 4 hours	1 (1%)	37 (28%)	35 (27%)	13 (18%)	25 (31%)	33 (37%)
>4 hours	77 (92%)	73 (55%)	70 (54%)	45 (61%)	21 (26%)	15 (17%)
Total	84	134	129	74	80	89

Source: Author's survey

Notes:
1. The average one-way driving time.
2. Totals may not add to 100% due to rounding.

The pattern emerging in Table 5.36 in relation to proximity for process innovation is that the agents with which businesses interact most frequently are not proximate. There is a significant difference between the proximity of each interaction agent [Pearson’s Chi-square = 129.603, df=10, p-value = 0.000]. There is no evidence of a difference in the proximity of academic-based researchers and innovation-supporting agencies [Pearson’s Chi-square = 2.284, df=2, p-value = 0.319]. Also, there is no evidence of a difference in proximity of suppliers, customers and competitors [Pearson’s Chi-square = 3.493, df=4, p-value = 0.479]. This indicates that interaction with the most important interaction agents for process innovation tends to occur over long distances. This is consistent with the findings for proximity for interaction for product innovation.

Appendix 6 contains an analysis of the proximity of interaction agents for process innovation by sector and nationality of ownership. This analysis shows that, unsurprisingly, foreign-owned businesses interact over greater distances than indigenous businesses with other group companies. Suppliers tend to be evenly distributed across the proximity ranges in the *Electronic Devices and Engineering* sector, while interaction with suppliers. Also, the innovation-supporting agencies with which indigenous businesses interact tend to be more proximate. There is no evidence of significant differences across sectors or ownership in the distance to interaction agents.

5.6. Competitive Environment

The final section of the questionnaire contains questions in relation to the competitive environment within which the participant's business operates. The questions are intended to shed light on the business' strategy in relation to product and process innovation. Question D.1 asks respondents to rate the importance of product and process innovation as a source of competitive advantage on a scale of 1 to 7, where a value of 1 means they are not important and 7 means that they are very important.

Respondents are also asked to indicate their perceptions of the degree of competition in their principal markets. In question D.2 they are asked to indicate the degree to which they believe that competition in the market for their primary good or service is intense in relation to price, product quality or all aspects. A value of 1 indicates that they strongly disagree that competition is intense and a value of 7 indicates that they strongly agree that competition is intense. Table 5.37 presents a summary of the responses.

Table 5.37 - Competitive Environment								
	ICT		**Electronic Devices**		**Chem/Pharm**		**Total**	
	Median	Mode	Median	Mode	Median	Mode	Median	Mode
Innovation is an Important Source of Competitive Advantage								
Product Innovation	7	7	7	7	6	6	6	7
Process Innovation	7	6	7	6	6	6	6	7
Competition is Strong in Relation to these Aspects								
Price	5	4	5	5	4	4	4	5
Product Quality	5	5	5	5	6	5	5	5
All Aspects	7	6	7	7	7	7	7	7

Source: Author's survey

The responses suggest that respondents across all sectors consider innovation, both product and process, to be a very important source of competitive advantage.

In relation to the nature of competition in the markets for respondents' primary goods and services, respondents in all sectors indicate that while competition is intense in all aspects, businesses tend to agree that competition is slightly more intense in terms of product quality than price.

5.7. Summary of Results

The previous sections have presented the descriptive results of the survey of 'high-technology' businesses in Ireland. This section summarises these results as follows. First the incidence of product and process innovation are reported, followed in order by findings in relation to R&D activity, interaction for product and process innovation and the spatial distribution of that interaction.

Four out of five businesses indicate that they introduced new products to the market between 2001 and 2003, and there is no statistical evidence of a difference in the proportion of product innovators across all sectors. The proportion of turnover accounted for by new products is 33% on average but is significantly higher in the *ICT* sector (50%) and lower in the *Chemicals and Pharmaceuticals* sector (19%). Indigenous businesses, on average, have a slightly higher proportion of turnover attributable to new products (38%) than foreign-owned businesses (27%), which is significant at a 90% confidence level. There is no evidence of a variance in the frequency of process innovation across sectors and between indigenous and foreign-owned businesses.

Indigenous businesses are significantly more likely to engage in R&D than foreign-owned businesses, though where they do engage in R&D foreign-owned businesses are significantly more likely to do so using a dedicated R&D department. Younger businesses are more likely to engage in R&D activity than older ones. Younger and smaller businesses tend to devote a greater proportion of turnover to R&D, though absolute employment in R&D tends to increase in line with overall employment in the business.

The frequencies of interaction with suppliers, customers and innovation-supporting agencies are all significantly positively correlated with both product innovation and process innovation.

The incidence and frequency of interaction for product innovation with group companies, suppliers and customers is significantly higher than it is with competitors, academic-based researchers and innovation-supporting agencies. Businesses in the *ICT* sector have significantly higher incidences of interaction for product innovation with suppliers and significantly lower incidences of interaction with academic-based researchers than the other two sectors. There is no evidence of a difference in the incidence of interaction with the other interaction agents across sectors. Indigenous businesses are significantly more likely than foreign-owned businesses to interact for product innovation with competitors and innovation-supporting agencies.

Interaction for process innovation is significantly more likely with group companies, suppliers and customers than it is with competitors, academic-based researchers and innovation-supporting agencies. *ICT* businesses are significantly less likely than businesses in other sectors to interact for process innovation with suppliers and innovation-supporting agencies. Foreign-owned businesses are more likely to interact with suppliers for process innovation than indigenous businesses. There is no evidence of a difference between indigenous and foreign-owned businesses in the likelihood of interacting with the other interaction agents for process innovation.

Group companies, suppliers and customers (the agents with which businesses are more likely to interact for product innovation) tend to be located at a greater distance than academic-based researchers and innovation-supporting agencies. In relation to interaction for process innovation, group companies, suppliers and customers tend to be located at a greater distance than academic-based researchers and innovation-supporting agencies.

5.8 Policy Implications

These results have important implications for Irish industrial policy and the effectiveness of policies to promote innovation in Ireland's high-technology businesses. Many of these policy implications have been presented in Jordan and O'Leary (2005). This section is structured as follows. First, the level of innovation in Irish high-technology businesses is considered. Second, the policy implications of the findings in relation to the drivers of innovation, R&D and interaction, are discussed. Third, the implications of the lack of localised interaction is considered. The results and conclusions from the descriptive analysis reported in this Chapter provides the basis of subsequent inferential analysis, reported in Chapters 6 and 7.

5.8.1 The Level of Irish Innovation

While this study is primarily concerned with the drivers of innovation in Irish high-technology businesses, the relatively high proportion of businesses that identified themselves as product innovators and regular process innovators is notable. Using R&D investment and patents as a measure of Irish business' innovativeness, the Department of Enterprise, Trade and Employment states that "our overall performance on the R&D and innovation indicators covered by EU and OECD studies can validly be described as poor to middling" (2003:119). While Ireland is below the OECD average in the number of applications per capita by high-technology businesses to the European and US Patent Offices (Department of Enterprise Trade and Employment, 2003:120), it has been discussed in Chapter 3 that patents are not a good measure of innovation output. Process innovations cannot be patented, some product innovations may not be patentable or may not be patented by businesses that wish to maintain secrecy regarding innovations.

Survey measures, such as those generated by this study, are a superior indicator of the level of innovation output. In this study four fifths of businesses introduced new or improved products in the three-year period between 2001 and 2003 and three quarters introduced process innovations on at least a regular basis. The European Innovation Scoreboard (2003), based on the Community Innovation Survey, in which there is no Irish data, finds that the EU average percentage of small and medium-sized businesses in high-technology and medium to high-technology sectors that "innovated in-house" is 78.3% and 67% respectively (European Commission, 2003a).

The proportion of product innovators in this study (80%) also compares favourably with other Irish innovation survey data, which was discussed in more detail in section 5.2.1. Breathnach (1996) finds that 62% of high-technology and medium to high-technology Irish businesses were product innovators between 1993 and 1995. Forfás (2005) estimates that 74% of Irish businesses introduced new products in the three years between 2001 and 2004. Roper (2001) finds that 61.8% of businesses on the island of Ireland indicated that they introduced new products between 1993 and 1996 and 53.8% introduced new processes. The favourable level of innovation output in this study may be explained by the focus on high-technology sectors and the broad definition of innovation used.

A similar favourable outcome is also seen in relation to innovation inputs such as R&D activity. The Department of Enterprise Trade and Employment reports that business expenditure on R&D as a percentage of GDP is three-quarters of the EU average and public expenditure on R&D as a percentage of GDP is just over half the EU average (2003: 120). Just as patents are not an ideal measure of innovation output, absolute levels of expenditure on R&D is not an ideal indicator of innovation inputs. Greater levels of investment on R&D do not necessarily mean greater levels of innovation, since the return to R&D is based on how well the investment is used, or R&D productivity, rather than the absolute level. Two-thirds of the businesses in this study indicated that they perform R&D. The percentage of indigenous businesses engaged in R&D is 80%. Roper (2001) finds that 47% of businesses across all sectors in Ireland perform R&D.

The evidence from this study suggests that Irish high-technology businesses perceive themselves as being innovative, which is a positive feature of this study. It may also indicate that studies of Irish innovation performance to date, which have largely been based on patent statistics and R&D expenditure, may underestimate the level of innovation performed in the Irish economy. Using patents and R&D expenditure as indicators of innovation performance reflects an emphasis on science and technology indicators. This emphasis was identified as a "clear deficit" of policy by the

Enterprise Strategy Group (2005:31). However, the recent *Strategy for Science, Technology and Innovation* (Department of Enterprise, Trade and Employment, 2006) indicates that this emphasis persists. This study adopts a broader definition of business innovation, which includes innovation that is not necessarily technological but which may be just as important for business competitiveness and growth.

5.8.2 The Drivers of Innovation in Irish High-Technology Businesses

With regard to the drivers of innovation in Irish high-technology businesses, recent science and innovation policy has focused strongly on raising the level of R&D undertaken in Ireland. Forfás (2000) recommended more focused direct support for in-company R&D to encourage first-time R&D performers and set a target that R&D as a percentage of turnover in manufacturing businesses would surpass the OECD target of 2.4% by 2010. There was a commitment to double public expenditure on research in third-level institutes to 1% of GNP by 2005. The recently published *Strategy for Science, Technology and Innovation* (Department of Enterprise Trade and Employment, 2006) renewed this emphasis on R&D as a key element of Irish enterprise and innovation policy. In this report the government commits to spend €3.8 billion on private sector and third-level research by 2013 with €2.8 billion to be spent before the end of 2008. The results of this survey provide qualified support for policies aimed at increasing the level of in-company R&D. The results show a positive association between R&D and the incidence of product and regular process innovation. This suggests that, while not controlling for other factors, businesses performing R&D tend to be innovative. There is tentative evidence here that where government measures to increase the level of in-company R&D are successful, higher incidences of product and process innovation may result.

However, this study suggests that there will be difficulties in achieving this objective. While businesses that performed R&D had higher incidences of product and process innovation, there is no evidence that a dedicated R&D department is positively associated with being an innovator. This means that innovating businesses are not performing R&D in a formal or routine way, as far as this can be measured by the presence of a dedicated department. This may make it difficult for policy makers to identify those businesses that are engaged in R&D and may bias funding towards those businesses that have dedicated departments for R&D, even though this study suggests that R&D that is less formal may be as effective in producing product and process innovation.

The results reported in this Chapter suggest that, as well as in-company R&D, interaction with other group companies, suppliers and customers is positively associated with business-level product and process innovation. The analysis presented in this Chapter does not facilitate comparison of the relative importance of R&D and interaction, which is addressed in Chapter 6. However, the finding of a positive association between interaction between businesses and innovation is consistent with the consensus in the Irish, and indeed the European, policy community that developing innovation through linkages and networks is important for future Irish and European competitiveness. The National Competitiveness Council, in its statement to the Enterprise Strategy Group (ESG), recommends support for developing networks to promote innovation within Irish businesses (2004:3). Forfás recommends that the Irish government focus on inter-business networks as a key building block in the development of the innovation capacity of Irish industry (2004a:7).

The ESG advocates networks involving industry, academic and public sector co-operation to drive the development of knowledge and expertise (2004: 53). This study provides evidence that businesses in Irish high-technology businesses interact strongly with group companies, suppliers and customers, though there is little evidence of similar levels of interaction with competitors, academic-based researchers and innovation-supporting agencies.

The survey shows that there is a low incidence of interaction, whether formal or informal, with competitors in order to promote innovation. The role of interaction and/or collaboration between competitors as a driver of innovation is based on a number of celebrated examples in places such as Silicon Valley, Emiglia-Romagna and Cambridge (Scott, 1988; Castells and Hall, 1994 and Forfás, 2004a), where the businesses are small and flexible, enabling alliances to form easily. These special cases may not be easily generalized (Gordon and McCann, 2005). In the case of Ireland, the applicability of this concept is open to question, as typically high-technology businesses located in the country are a mix of very large foreign-owned and smaller indigenous businesses, operating in particular international market niches, with few competing with each other.

The survey also finds infrequent interaction between Irish high-technology businesses and academic-based researchers. This finding raises doubts about whether increased funding for research in third-level institutes will produce the desired business-level innovation. This study indicates that there is a low incidence of interaction for innovation with third-level institutions, which raises questions about how to achieve a better understanding of how such linkages can be fostered and developed, in order to achieve the best possible future return from publicly funded research. It should be noted that while the descriptive analysis reported earlier in this Chapter indicates a low level of interaction with academic-based researchers it does not shed light on the effect of the interaction on business innovation where it does occur.

The analysis undertaken in Chapter 6 explores whether such interaction has a positive effect on business level interaction while controlling for other factors. Notwithstanding this qualification, the results presented here provide an early warning signal to policy makers in relation to a critical aspect of the long-term objective of building a knowledge-based economy and promoting innovation as a source of future competitiveness. Funding for basic research, such as that proposed in the *Strategy for Science, Technology and Innovation* (Department of Enterprise Trade and Employment, 2006) can contribute to growth and competitiveness only where it is applied commercially. Interaction between business and academic-based researchers is crucial to identifying the commercial value of publicly-funded basic research.

Evidence that this interaction is not taking place, or is infrequent, should be a cause of concern for policy makers, since longer-term goals may not be achievable.

The finding of infrequent interaction for innovation with innovation support agencies is also notable, as these institutions, as part of their role, facilitate the process of developing linkages at local/regional level. For example, Enterprise Ireland is responsible for the National Linkage Programme.

The results discussed above are based on bivariate descriptive analysis, and further analysis is required to estimate the relative importance of in-company R&D and interaction as drivers of innovation in Irish high-technology businesses, while controlling for business characteristics that are found in this Chapter to be associated with innovation output. This is the focus of Chapter 6, in which an innovation production function approach to modelling the drivers of innovation is presented and estimated.

5.8.3 Geographical Proximity and Interaction for Innovation

As noted in section 2.6, there is a wide theoretical literature suggesting that knowledge spillovers through interaction may be spatially bounded. Policy prescriptions, since the publication of the Culliton Report (1992), have also implied an important role for geographic proximity in promoting interaction for innovation by promoting the development of local or regional clusters around internationally competitive sectors. Particularly important in this context have been measures for embedding foreign-owned businesses. Irish regional policy has also advocated clusters, with the National Spatial Strategy envisaging gateways as having “large clusters of national/international scale enterprises, including those involved in advanced sectors” (Department of the Environment and Local Government, 2002:40). This policy emphasis has been influenced, as it has been in other EU countries, by the performance of particular industrial clusters, which have been associated with strong innovation performance, such as Silicon Valley, Emiglia-Romagna in Italy and the science-based cluster in Cambridge, UK. These clusters have been highlighted by the work of authors such as Scott (1988), Saxenian (1990) and Castells and Hall (1994).

However, from the perspective of innovation, Gordon and McCann (2005) have argued that these are an idealised type of cluster, which may not be superior to alternative agglomerations, arising from localisation, urbanisation or, what Parr refers to as, activity complex economies (2002). In this regard it is notable that the ESG attaches little importance to the role of geographic proximity for the promotion of innovation. For example, it includes the implementation of the National Spatial Strategy as an essential condition, but not one of the five key sources of competitive advantage (2004:97-8).

While noted earlier that this study provides some evidence of a positive relationship between interaction and innovation in Irish high-technology businesses, there is little to support geographically bounded knowledge spillovers. The findings indicate the absence of strong interaction for the purpose of promoting innovation between locally or regionally based concentrations of suppliers, customers, competitors, academic-based researchers and innovation-supporting agencies. These findings raise questions about the particular type, if any, of local/regional clusters and networks, which might reasonably be expected for the promotion of innovation in Irish high-technology businesses.

Given the long-standing industrial policy of building competitive advantage on the back of foreign direct investment by successful high-technology businesses, it is perhaps not surprising that the survey found that interaction with other group businesses is strong and occurs over long distances. Love and Roper (2001) also find that technology transfer within multinational enterprises in Ireland is relatively high. The importance of foreign multinationals to the Irish economy, the limited size of the domestic market and the associated value of international selling may explain why most important interactions by foreign-owned and indigenous businesses with customers are not local or regional. Despite repeated efforts devoted to building backward linkages locally and regionally, especially between foreign-owned and indigenous businesses, it is notable that the survey finds interaction between high-technology businesses and suppliers for the purpose of promoting innovation occurs over long distances. This is a cause for concern, particularly in the context of continued state funding devoted to developing networks and clusters.

Overall, the survey results suggest a limited role for geographical proximity in regard to innovation by Irish high-technology business. This may be partly due both to the distinctive development of Ireland’s internationally competitive industry, with the dominance by foreign-owned businesses, and to the small size of the country. However, it may also be attributable to Ireland’s undeveloped regional innovation systems, which currently seem to have little to offer these businesses in pursuit of enhanced innovation performance. These results form the basis for inferential analysis reported in Chapter 7 which focuses on the spatial dispersion of interaction for innovation. The analysis reported in this Chapter tests whether localisation and/or urbanisation economies impact on innovation in high-technology businesses. This Chapter has important implications for Irish regional and enterprise policies, which, as noted above, emphasise the importance of clusters for economic development.

5.8.4 Deepening the Analysis

In addition to being able to identify a number of policy implications from the statistical descriptive analysis, the results reported in this Chapter also indicate that further statistical inferential analysis of the data using econometric techniques is necessary to identify the relative importance of drivers of innovation. In particular, a crucial question is whether R&D effort and/or interaction are important drivers of product and process innovation in Irish ‘high-technology’ businesses. This issue is the focus for Chapter 6, which presents an innovation production function modelling product and process innovation output as a function of internal R&D effort and interaction for innovation with other businesses and institutions, while controlling for relevant business characteristics. The Chapter reports three estimations using product innovation output indicators. These are the incidence of product innovation, product innovation intensity, measured by the number of new products introduced per 100 employees, and innovation success, measured by the percentage of turnover attributable to newly introduced products. There are two process innovation estimations, using the incidence of process innovation and the frequency of process innovation as the dependent variables. These estimations shed light on the relative importance of the drivers of innovation in Irish high-technology businesses. The policy implications of the results of this analysis are discussed in the final section in Chapter 6.

Chapter 8 summaries the key results of the previous three Chapters and summaries the policy implications.

CHAPTER 6: WHAT DRIVES INNOVATION IN IRISH HIGH-TECHNOLOGY BUSINESSES? - AN INNOVATION PRODUCTION FUNCTION APPROACH

Chapter 5 presents statistical descriptive analysis of the survey of Irish high-technology businesses. The results suggest a positive relationship for each sector between innovation outputs, both product and process, and research and development (R&D) and interaction with group companies, suppliers, customers, competitors, academic-based researchers and innovation-supporting agencies. In addition there are positive correlations between R&D and product and process innovations. Also, product innovators and regular process innovators indicated a higher incidence of interaction across all interaction agents than non-innovators.

This Chapter builds on the empirical analysis presented in the previous Chapter and reports statistical inferential analysis using appropriate econometric techniques. This analysis explores the relationship between innovation outputs and innovation inputs and estimates the relative importance of R&D and interaction in explaining the innovation activity of Irish high-technology businesses. The relationships are estimated using several different indicators of innovation inputs and outputs. The first section of the Chapter presents the method used to estimate the relationships and the different indicators used. As well as indicators of innovation activity, R&D and interaction, there are several business specific characteristics which are used as controlling variables in the various estimations.

The second section is concerned with product innovation. In this section, three indicators of product innovation output are considered. The first, a binary variable, is whether or not a business has introduced a new product or not over the three-year reference period. The second indicator of product innovation is the intensity of product innovation, measured by the number of product innovations introduced in the three-year period between 2001 and 2003 divided by the number of employees. The third and final indicator is the success of product innovation, measured by the proportion of sales in 2003 that are attributable to new products introduced in the previous three years. The definitions of product innovation corresponding to these measures are discussed in Section 2.2.3 in Chapter 2.

The third section presents the results of estimations of the determinants of process innovation. Two indicators of process innovation are considered. The first is a binary variable representing whether or not a business indicated that it introduced process innovations on at least a regular basis over the three-year reference period. The second indicator is the frequency with which process innovations are introduced to the business. The definitions of process innovation corresponding to these measures are discussed in Section 2.2.3 in Chapter 2.

The final section summarises the results of the various estimations presented and discusses the policy implications arising.

6.1 Method of Estimating Innovation Output

The approach adopted here is to specify an innovation production function. The use of an innovation production function in this thesis is based on similar approaches in Acs and Audretsch (1988), Geroski (1990), Harris and Trainor (1995), Audretsch and Feldman (1996), Love and Roper (2001), Oerlemans et al (2001), Roper (2001) and Freel (2003). Freel refers to this approach as "established practice of modelling innovation output" (2003:756) and models innovation output as a function of internal resources dedicated to innovation, external sources of knowledge for innovation and the characteristics of the business that affects innovation activity. In this thesis the innovation production function takes the form:

$$I_i = \alpha_0 + \alpha_1 Z_i + \alpha_2 R_i + \alpha_3 N_i + \mu_i \qquad \text{[Equation 6.1]}$$

where I_i is an indicator of innovation output in business i.
Z_i is a range of business-specific factors that may affect business i's capacity to innovate
R_i is an indicator of R&D effort in business i.
N_i is an indicator of the extent of interaction for innovation in business i.

The survey data used to estimate the innovation production function provides several indicators of I_i, R_i and N_i. Zi is a range of indicators representing business characteristics for which the estimation must be controlled. These are set out below.

6.1.1 Measures of Innovation Output

Five measures of innovation output, referred to as I_i in Equation 6.1, are considered. The technique used to estimate the innovation production function varies with each indicator of innovation output. For example, whether a business has introduced a new product or not produces a binary variable, so that logit estimation is appropriate. Innovation success is measured as the percentage of turnover attributable to new products. In this case therefore, the dependent variable has lower and upper limits of zero and 100%, so that tobit estimation is appropriate.

The measures of innovation output used in this study are presented in Table 6.1, along with a definition of each measure, the appropriate estimation technique for each output measure and references to other studies that have adopted the same approach. These measures are similar to those used in similar innovation studies, which are referenced in Table 6.1 and discussed in detail in Chapter 3.

Table 6.1 – Innovation Output Indicators (I_i) and Appropriate Estimation Techniques for Each Indicator

Product Innovation Output Measure	***Definition***	***Estimation Technique***
Product Innovator	A binary variable taking a value of 1 if the business introduced at least one new product in the three-year period between 2001 and 2003.	Logit model of the probability of introducing a new product (Roper, 2001, Love and Roper, 2001, Freel, 2004)
Product Innovation Intensity	The number of new products introduced in the three-year period between 2001 and 2003 per 100 employees.	Tobit Regression for Limited Dependent Variables (Roper, 2001)
Innovation Success	The percentage of 2003 turnover attributable to new products introduced in the three-year period between 2001 and 2003.	Tobit Regression for Limited Dependent Variables (Roper, 2001)

Table 6.1 continued – Innovation Output Indicators (I_i) and Appropriate Estimation Techniques for Each Indicator		
Process Innovation Output Measure	***Definition***	***Estimation Technique***
Regular Process Innovator	A binary variable taking a value of 1 if the business introduced new processes with at least regular frequency in the three-year period between 2001 and 2003.	Logit model of the probability of introducing new processes on at least a regular basis. (Roper, 2001, Love and Roper, 2001, Freel, 2004)
Frequency of Process Innovation	An ordinal variable taking a value between 1 and 5 representing the frequency of new process innovation, where 1 means no process innovation and 5 means continuous process innovation.	Ordered Logit Model of the Probability of Introducing New Processes at Each Frequency

Source: Author's survey

6.1.2 Measures of the Inputs to Innovation

In the innovation production function presented above the dependent variables include business characteristics, R&D effort and interaction. The indicators to measure these variables are presented below.

6.1.2.1 Business Characteristics

The business-specific factors, referred to as Z_i in Equation 6.1 are set out in Table 6.2. Their selection is based on other empirical studies which are also referenced for each indicator in Table 6.2.

Table 6.2 – Business Characteristics Affecting Innovation Capacity (Zi)		
Business Characteristics Indicators	***Definition***	***References***
Age	The number of years at the start of the reference period since the business began operations in Ireland.	Roper (2001), Freel (2003)
Size	The number of employees (full-time equivalent) at the start of the reference period.	Malerba and Orsenigo (1995), Love, Ashcroft and Dunlop (1996), Roper (2001), Freel (2003)
Profitability	Net profit as a percentage of turnover in 2003. Measured using intervals of 5%.	Oerlemans, Meeus and Boekema (2001)
Foreign Ownership	A dummy variable taking a value of 1 if the business is foreign-owned.	Love, Ashcroft and Dunlop (1996), Roper (2001)
Group Member	A dummy variable taking a value of 1 if the business is a parent or subsidiary in a larger group of companies.	Love, Ashcroft and Dunlop (1996), Roper (2001)
Workforce Education	The percentage of the workforce that have a third-level degree or equivalent qualification.	Cohen and Levinthal (1990), Love and Roper (2001a), Roper (2001), Freel (2003)
Turnover Growth	The rate of growth in turnover in the three-year period between 2001 and 2003.	Love and Roper (2001a), Roper (2001)
Sector	A series of dummy variables; the sectors controlled for are *ICT* and *Chemicals and Pharmaceuticals*. The reference sector is *Engineering and Electronic Devices*.	Most innovation studies control for sectoral differences. A sample of these are Roper (2001), Freel (2003), Oerlemans, Meeus and Boekema (2001), Love, Ashcroft and Dunlop (1996)

Source: Authors survey

The survey on which the study is based generated data on other aspects of Irish high-technology businesses. This includes

- the location of the business;
- for foreign-owned businesses, the country in which headquarters are located;
- the number of products and/or services the business offered to the market at the start and end of the reference period;
- the number of employees in the business at the end of the reference period and
- whether the business is a member of a business association or lobby group.

Respondents also indicated the extent to which their business' competitive environment is intense in relation to price, quality and all aspects of competition. They also indicated their perceptions of the importance of product and process innovation as a source of competitive advantage for their businesses.

These variables are only reported in subsequent estimations if their inclusion improves the explanatory power of the these estimations.

6.1.2.2 R&D Indicators

The survey data contains several indicators of R&D effort, referred to as R_i in Equation 6.1. These variables and their definitions are presented in Table 6.3.

Table 6.3 – Indicators of Business-Level R&D Effort (R_i)	
R&D Indicators	***Definition***
R&D	A binary variable taking a value of 1 if the business performed R&D in the three year period from 2001 to 2003.
R&D Department	A binary variable taking a value of 1 if the business had a dedicated R&D department in the three year period from 2001 to 2003.
R&D Spending	A series of binary variables of R&D expenditure as a percentage of turnover; categories are <5%, 6% to 10% and >10%. The reference group is no expenditure on R&D.

Source: Authors survey

The survey also generates data on the number of employees in R&D departments during the three-year period between 2001 and 2003, the level of financial assistance for R&D received from innovation-supporting agencies as a proportion of R&D the business' total R&D expenditure and, if the business is a member of a group, whether other businesses in the group had a dedicated R&D department. These variables are only reported in estimations presented in this Chapter if their inclusion improves the explanatory power of the estimations.

6.1.2.3 Interaction Indicators

This study contains new indicators of the extent of interaction between businesses and between businesses and other institutions. This is the first study to measure the frequency of interaction with a range of interaction agents for both product and process innovation. The structure of the survey question provides two measures of interaction with each of the six interaction agents and a third measure is constructed based on the aggregate level of interaction across all agents undertaken by the business.

The six interaction agents considered are other group companies, suppliers, customers, competitors, academic-based researchers and innovation-supporting agencies. The frequency of interaction with each agent is measured on a five point scale, ranging from never to rarely, regularly, frequently and continuously. This generates an ordinal variable for each interaction agent representing interaction frequency where a value of 1 represents no interaction up to 5 representing continuous interaction. The frequency of interaction is considered for both product and process innovation. A binary measure of the incidence of interaction with each interaction agent is also generated, taking a value of 1 if business i indicates that it interacted for innovation with a particular agent at any frequency level during the three year period between 2001 and 2003, and a value of 0 if it indicates that it never interacted.

In the estimations that follow a binary variable representing business i's membership of a group of companies is used as a proxy measure of interaction with other group companies for innovation. This variable takes a value of 1 if the business is a member of a group of companies. This is necessary as interaction with other group companies can only arise for those businesses that are part of a group in the first instance. Therefore, using the group interaction variable would significantly reduce the number of observations in each estimation (there are 106 group companies in the database). Also a very large majority of group companies (95%) indicated that they interacted with other group companies for product and process innovation. Therefore, the ownership binary variable is used as an indicator of the incidence of interaction for innovation with other group companies. In relation to the frequency of interaction, group company interaction is not considered. There is very little variation in the variable measuring the frequency of interaction with group companies. Of those businesses that interacted with other group companies, 90% did so continuously or frequently. The loss of observations for those respondents that are stand-alone businesses means that it is not worthwhile to include frequency of interaction with other group companies in any of the following estimations.

A composite indicator of the extent to which a business utilises external sources of knowledge for innovation is generated from the frequencies with which a business interacts with the range of external interaction agents. This variable, which is referred to as Interaction Score, indicates the frequency with which a business interacts with the range of external interaction agents. The measure is constructed so that a business that interacts with a diverse range of interaction agents has a higher Interaction Score than a business which interacts, albeit continuously, with one interaction agent. Jacobs (1969) and Glaeser et al (1999), in explaining the growth of cities, argue that diversity of interaction is an important aspect of learning for innovation. This interaction indicator attempts to measure the diversity of interaction for innovation.

The indicator is measured as the sum of the values for interaction frequency with each interaction agent, excluding other group companies. Interaction with group companies are excluded as not all businesses in the sample are members of a group of businesses. Their inclusion would overstate the interaction diversity of businesses that are members of larger groups relative to stand-alone businesses. The interaction frequency variable for each interaction agent takes a value of 1 if interaction does not occur, 2 if it occurs rarely, 3 if regularly, 4 if frequently and 5 if continuously. So, if a business does not interact for innovation with any agent that business would have an Interaction Score of 5 (i.e. 1 for each of the 5 interaction agents). A business that interacted frequently with all interaction agents would have an interaction score of 25 (i.e. 5 for each of the 5 interaction agents). The scores are not weighted as this would require a judgement on which agent is more important as an interaction agent for each business. While in Chapter 5 it is seen that most businesses tend to interact most frequently with suppliers and customers, at the individual business level there is no basis for believing any one agent is a more important source of knowledge for innovation than any other and it is not possible *ex ante* to say from which interaction agent knowledge for innovation comes.

The measure is constructed so that a business which interacts, even rarely, with all of the external interaction agents has a higher interaction score (2 for each of the five interaction agents resulting in a score of 10) than a business that interacts continuously with just one (5 for interacting with continuously with one agent and 1 for each of the other agents resulting in a score of 9). The indicator implies that businesses that have a wider network of interaction are 'more interactive' than those businesses which interact only with one agent. As discussed in Chapter 2, following Glaeser, who states that "diversity generates the most important ideas" (1999:257), it may be expected that a more diverse range of contacts improves the business' innovation performance. The estimations below test whether innovation is affected by the range or diversity of networks for interaction as well as the frequency of interaction.

6.2 Estimating the Innovation Production Function for Product Innovation

This section presents the results of estimations of the innovation production functions for product innovation.

6.2.1 Estimation of the Probability of Introducing New Products

Table 6.4 reports a logit estimation of the probability that businesses introduced new products in the three-year period between 2001 and 2003.

The independent variables in this and subsequent tables are categorised into three sections. The first refers to business characteristics, the second to indicators of R&D activity and the third to interaction with a range of interaction agents.

Table 6.4 Logit Model of the Probability of Introducing New Products

	Coefficients[1]	Z-value[2]	Weighted Elasticities
Business Characteristics			
Age	0.0392	2.13*	0.0245
	(0.0184)		
Size	-0.0016	-1.29	-0.0022
	(0.0013)		
Turnover Growth	0.0477	0.32	0.0024
	(0.0859)		
Foreign Ownership	-1.4596	-1.07	0.0027
	(1.3591)		
Workforce Education	0.0046	0.45	0.0054
	(0.0107)		
Sector[3]			
ICT	-0.6364	-0.94	0.0020
	(0.6773)		
Chemicals and Pharmaceuticals	-1.2089	-1.89**	-0.0082
	(0.6384)		
Research and Development			
Perform R&D	1.2089	1.88**	0.0419
	(0.6415)		
R&D Department	0.7888	1.06	0.0140
	(0.7904)		
Interaction			
Frequency of Interaction with:			
Supplier	0.4145	1.96*	0.0496
	(0.2150)		
Customer	0.5786	2.63*	0.0979
	(0.2200)		
Competitor	-0.3025	-1.14	-0.0161
	(0.2649)		
Academic	-0.7119	-2.28*	-0.0359
	(0.3121)		
Agency	0.7803	2.37*	0.0486
	(0.3287)		
Group Member	1.7386	1.30	-0.0020
	(1.3373)		

Table 6.4 continued - Logit Model of the Probability of Introducing New Products			
	Coefficients[1]	Z-value	Weighted Elasticities
Constant	-2.9306	-2.42*	
	(1.2089)		
N	175		
Log Likelihood	-57.189		
Pseudo R^2	0.3363[4]		
LR X^2	57.95		
	(0.0000)		
Percentage Correctly Predicted			
Overall	86.3%		
Innovator	89.3%		
Non-Innovator	69.2%		

Source: Authors survey

Notes:
1. The figures in parentheses are standard errors of the coefficients.
2. * Significant at 5% level.
   ** Significant at 10% level.
3. The reference sector is *Electronic Devices and Engineering*
4. Pseudo R^2 reported is the likelihood ratio index (i.e. $1\text{-}\ln L/\ln L_0$, where L_0 is the log likelihood computed with only a constant term).

The number of observations in the estimation presented above is 175, which implies there are 9 missing cases. These missing cases arise because respondents may not have provided data on one of the variables included in the model. The approach adopted is to omit those cases for which data is missing. While this reduces sample size, assuming that these values are missing at random, the listwise deletion approach adopted results in unbiased parameter estimates. Estimating the missing values using regression is not found to increase the explanatory power of the estimation. This approach is also adopted for the other estimated models presented in this Chapter.

Table 6.4 presents weighted elasticities for each variable. Traditionally, elasticities are estimated at the sample means of the explanatory variables. This approach however has been criticised. Since the elasticities are non-linear functions of the observed data, the estimated logit function need not pass through the point defined by these sample averages (Hensher and Johnson, 1981; Train, 1986). Hensher and Johnson note that using sample means usually over-estimates elasticities by up to 20%. (1981:59). Westin finds that elasticities computed using the sample mean over-estimated aggregate elasticities by 28.5% (1974:10). To address this difficulty, Hensher and Johnson suggest estimating elasticities at every observation and then constructing a weighted average using the predicted probabilities as weights. Reid argues that it is desirable to compute Hensher-Johnson weighted elasticities to assist in interpreting logit models (2000:74). This approach is adopted in this case and the weighted elasticities presented in Table 6.4 are Hensher-Johnson elasticities. For other logit estimations (in Tables 6.8 and 7.5) Hensher-Johnson weighted elasticities are also reported.

Interpretation of Estimation Results

In Table 6.4, the age variable is significant at a 95% confidence level with a positive coefficient of 0.0392. Since this is a logit estimation, this means that each additional year of operation increases the logged odds of product innovation by 0.0392. To interpret the estimated coefficients more easily and identify the effect of each variable on the odds of product innovation, the estimated coefficient is exponentiated. An estimated coefficient of 0.0392 therefore means that an extra year in operation increases the odds of product innovation by a factor of 1.04 (or $e^{0.0392}$) (Pampel, 2000; Hosmer and Lemeshow, 2000; Menard, 2002). Estimated coefficients in all subsequent models are interpreted in a similar manner. The Hensher-Johnson weighted elasticity of the age coefficient is 0.0245, which means that a 1% increase in the age of a business will increase the probability of introducing new products by 2.45%. The weighted elasticities indicate the relative importance of each significant predictor of the probability of introducing new products. However, these elasticities cannot be interpreted in the same way for the interaction variables since they are ordinal variables.[1]

None of the other business characteristic variables reported in the estimations are significant predictors of the probability of introducing new products. In particular it is noticeable that workforce education and business size are insignificant. The insignificant business characteristics includes those variables referred to in Section 6.1.2.1 which are not included in the reported estimations as they did not improve the explanatory power of the estimations.

In Chapter 3 it is noted that there is mixed evidence from empirical literature on the effect of business size on innovation. This study does not find a similar result to Roper (2001) and Freel (2003) that size has a small positive effect on the probability of introducing new or improved products. There is evidence in empirical literature to

[1] An alternative approach is to re-estimate the model using a series of dummy variables for each frequency interval for all interaction agents. While this would enable one to compare elasticities of interaction frequencies, it would reduce the explanatory power of the model overall by reducing degrees of freedom.

suggest that size has a J-curve effect on innovation output, meaning there are higher levels of innovation in very small businesses and very large businesses, while businesses in-between tend to exhibit lower rates of innovation. The indicator of business size in Table 6.4 is the number of employees at the start of the reference period, so a J-curve effect cannot be tested. However, the model was also estimated using a categorical measure of business size based on the EU definition of micro (<10 employees), small (10-49 employees), medium (50-249 employees) and large (250+ employees) enterprises. With micro-sized businesses as the reference category, none of the size categories had a significant effect on the probability of product innovation, providing no evidence of a J-curve effect for Irish high-technology businesses.

It is notable in Table 6.4 that workforce education is not significantly associated with product innovation. Both Roper (2001) and Freel (2003) find a significant positive relationship between the level of skill in the workforce and the probability of product innovation. Roper (2001) measures skills levels as the percentage of graduates in the workforce, which is also the measure used in this study. Freel (2003) adopts two measures, the first is the percentage of the workforce classified as technicians and the second is the percentage classified as technologists or scientists. In Freel's (2003) study however he categorises businesses into sectors using Pavitt's (1984) taxonomy. For science-based businesses he finds no significant relationship between workforce skills levels and the probability of product innovation. This result, taken with the findings in Table 6.4, suggests that educational or skills levels in high-technology and science-based businesses do not affect the probability of product innovation.

The estimated coefficient for the dummy variable representing the *Chemicals and Pharmaceuticals* sector is significant and negative, indicating that businesses in this sector are significantly less likely to be product innovators relative to the reference sector, *Engineering and Electronic Devices*. This effect however is very small, the weighted elasticity is -0.0082, which indicates that, relative to *Electronic Devices and Engineering businesses,* businesses in the *Chemicals and Pharmaceuticals* sector are 0.82% less likely to be product innovators.

R&D has a positive and significant effect on the likelihood of introducing new products. Performing R&D is a binary variable, so the estimated coefficient greater than 1 indicates that those businesses that performed R&D are more likely to have introduced new products than those that did not perform R&D. The logged odds of being a product innovator are 1.2089 times greater for businesses performing R&D than for those not performing R&D. This means that the probability of introducing new products is 3.35 times greater for businesses that perform R&D. The relatively large and positive association between R&D and the probability of product innovation is consistent with other empirical innovation studies (Acs and Audretsch, 1988; Love, Ashcroft and Dunlop, 1996; Roper, 2001; Freel, 2003; Becker and Dietz, 2003).

The dummy variable representing the presence of a dedicated R&D department is not significant. Together with the result for R&D, this suggests that while the presence of R&D may be important, performing it in a dedicated department does not have a significant effect on product innovation output. This finding is not consistent however with Roper (2001) which finds that both performing R&D and having an R&D department have a positive effect on the likelihood of a business introducing new or improved products.

Four of the six interaction variables have significant associations at a 95% confidence level with the probability of being a product innovator. There are positive relationships between the likelihood of product innovation and the frequency of interaction with suppliers, customers and innovation-supporting agencies. This indicates that businesses that interact more frequently with these agents have a higher probability of introducing new products to the market. A one unit increase in the frequency of interaction with suppliers and customers increases the odds of being a product innovator by factors of 1.51 and 1.78 respectively. The weighted elasticities of these variables are large relative to the other significant variables in the estimation. A one-unit increase in the frequency of interaction with suppliers increases the probability of product innovation by 4.96%, while a one unit increase in the frequency of interaction with customers increases the probability of product innovation by 9.79%.

The findings in relation to the interaction variables are generally consistent with Roper (2001) and Freel (2003), though some differences are discussed in the analysis that follows. Roper (2001) finds a positive association between interaction with external businesses and organisations and the probability of product innovation, which is supported by the findings reported in Table 6.4. Freel (2003) finds that interaction with both customers and public sector agencies have significant and positive effects on the likelihood of introducing product innovations that are new to the industry.

Freel (2003) also finds a significant positive association between interaction with customers and innovation-supporting agencies and the probability of introducing products that are new to the market.

In the previous Chapter it is reported that businesses interact less frequently for product innovation with innovation-supporting agencies than suppliers and customers (see Table 5.20). The estimation above shows that the frequency of interaction with innovation-supporting agencies has a significant and positive effect on the probability of innovation. The weighted elasticity is the same size as the frequency of interaction with suppliers.

A particularly notable result from the estimation above is the negative association between the frequency of interaction with academic-based researchers and the likelihood of product innovation. The effect is significant and also quite sizeable. A one unit increase in the frequency of interaction with academic-based researchers reduces the odds of product innovation by a factor of 2.12. This is an interesting result not found in other literature.

This suggests that businesses interacting with academic-based researchers are less likely to introduce new products. Kline and Rosenberg (1986), in presenting the chain link model of innovation discussed in Chapter 2, contend that at each stage in the innovation process, if a technical problem needs to be solved the first source of a solution is the stock of knowledge. Where a solution is not found then basic research may be needed. The results reported above may suggest that businesses may turn to academic-based researchers when faced with particularly difficult or complex problems during the process of innovation. Therefore, interaction with academic-based researchers may not reduce the likelihood of product innovation, but rather the businesses that interact with academic-based researchers are engaged with complex or emerging technologies where the likelihood of developing a commercial product is low. This finding suggests that further research into the nature of the interaction between business and academic-based researchers is worthwhile. This is considered further in the final Chapter when a research agenda emerging from this study is presented.

The estimated coefficient for interaction with competitors is insignificant, which means there is no evidence that sharing knowledge with competitors enhances the likelihood of innovation. Saxenian (1996) contends that the innovative output of Silicon Valley was supported by interaction between competitors based on a high degree of trust. Marshall refers to knowledge being “in the air” (1920:271) where there is a concentration of similar businesses. This implies knowledge sharing between competitors. The results of the estimation above do not provide any evidence that interaction between competing businesses increases product innovation output in Irish high-technology businesses.

The estimated coefficient for membership of a group of businesses is insignificant, indicating that interaction with other group companies does not affect the probability of introducing new products. This is consistent with Roper who finds “intra-group transfers of knowledge or technology are not particularly important in increasing the probability that plants will introduce new or improved products” (2001:221). This suggests that Irish branch plants of foreign multinationals are not engaged in new product development for the group but are concerned primarily with production or assembly of products developed elsewhere.

The results of this logit estimation suggest that internal and external sources of knowledge for innovation have significant effects on the likelihood of product innovation, and are broadly consistent with other empirical innovation studies.

Overall, the model is significant. The likelihood ratio (LR) X^2 tests the hypothesis that there is no difference between the estimated model and the constant only model (i.e. that each coefficient is zero). The p-value (0.0000) is less than 0.05, which indicates that this hypothesis can be rejected and the estimated model is a significant indicator of the probability of product innovation. The estimation reported in Table 6.4 has the greatest explanatory power relative to alternative estimations. This is based on the overall significance of the estimation, the largest log likelihood (-57.189), the highest pseudo R^2 (0.3363) and the highest percentage of observations correctly predicted by the model (86.3%). Appendix 7 contains alternative estimations of the probability of introducing new products, illustrating how the addition of each category of dependent variable increases the explanatory power of the model. Tests for multicollinearity are reported in Appendix 8, which indicate that multicollinearity is not a problem in this model and variances and standard errors are not overstated.

Similar analyses of multicollinearity are conducted for subsequent estimations. However, since many of the same variables are used in these subsequent estimations the results are similar to those presented above and are not reported.

The model presented above indicates that R&D and interaction increase the likelihood of innovation. However, this prompts the question whether these factors increase the level of product innovation within a business or the success of innovation within that business. The focus has been on the incidence of product innovation, though businesses are more or less innovative than others or their sales of new products may be a greater or lesser proportion of total turnover. These are measures of the intensity and success of product innovation. Thus, while R&D and interaction have so far been shown to positively affect the incidence of product innovation, the next sections consider whether they positively affect the ability of a business to introduce successive and successful new products.

6.2.2 Tobit Estimation of Product Innovation Intensity

A measure of product innovation output that indicates the relative innovativeness of a business is the number of new products introduced during the reference period. Of course it is not useful to compare absolute numbers of new products, as it is necessary to control for business characteristics. This study adopts the same measure of innovation intensity as Roper (2001), which is the number of new products introduced per 100 employees.

Since some businesses did not introduce any new products, their innovation intensity is zero. This means that the dependent variable in the estimation of product innovation intensity is censored at a lower limit of zero. A tobit estimation is appropriate for models with limited dependent variables (Davidson and MacKinnon, 1993). Table 6.5 reports the results a Tobit estimation of product innovation intensity. Alternative estimations of this model using different indicators for the independent variables are presented in Appendix 9.

The likelihood ratio (LR) X^2 is significant, so the hypothesis that there is no difference between the estimated model and the constant only model can be rejected. The model does not have as good a fit as that presented in Table 6.4. The Pseudo R^2 is lower and the LR Chi-square is less significant. The variables used in this estimation of product innovation intensity are similar to those reported in the logit estimation of the probability of product innovation in Table 6.4. Multicollinearity diagnostics are reported for these variables in Appendix 8 and since similar results are found for the tobit estimation of product innovation intensity these results are not reported. Multicollinearity tests indicate that multicollinearity is not a problem in this estimation.

It was noted in Table 6.4 that age had a significant effect on the likelihood of product innovation. In Table 6.5 it is seen that business age is not significantly associated with the intensity of product innovation, as measured by the number of new products per 100 employees. In Table 6.5 it is also seen that business size is not significantly associated with the intensity of product innovation.

With the exception of Turnover Growth the other business characteristics variables that are insignificant in Table 6.4 are also insignificant in Table 6.5. The rate of increase in turnover is positively associated with the intensity of innovation. Faster sales growth results in higher levels of product innovation intensity. Growth in turnover between 2001 and 2003 is measured on a 12-point interval scale, the first point representing a decline in turnover, with 10 intervals of 10% each and the final point representing turnover growth of greater than 100%. The results suggest that moving to the next highest point of the scale increases the number of new products per 100 employees by 0.13. This positive association may arise as businesses respond to growing sales volume by introducing product improvements to maintain market share. It may also be that sales grow faster in response to new products coming onto the market.

Table 6.5 – Tobit Model of Innovation Intensity

	Coefficient[1]	t-statistic[2]
Business Characteristics		
Age	0.0040	0.36
	(0.0111)	
Size	-0.0012	-1.13
	(0.0010)	
Turnover Growth	0.1557	2.86*
	(0.0544)	
Foreign Ownership	0.0727	0.12
	(0.6151)	
Workforce Education	-0.0004	-0.05
	(0.0073)	
Sector[3]		
ICT	-1.2196	-2.55*
	(0.4780)	
Chemicals and Pharmaceuticals	-0.5270	-1.15
	(0.4582)	
Research and Development		
Perform R&D	0.7730	1.53
	(0.5043)	
R&D Department	0.4566	1.00
	(0.4571)	
Interaction		
Frequency of Interaction with		
Supplier	-0.1904	-1.21
	(0.1571)	
Customer	0.3496	1.78**
	(0.1959)	
Competitor	-0.1443	-0.83
	(0.1734)	
Academic	-0.3409	-1.85**
	(0.1847)	
Agency	0.0503	0.26
	(0.1924)	
Group Member	0.2885	0.48
	(0.6018)	

Table 6.5 continued – Tobit Model of Innovation Intensity		
	Coefficient[1]	Z-Statistic
Constant	-0.8132 (0.9343)	-0.87
N	175[4]	
Log Likelihood	-319.01	
Pseudo R^2	0.0457	
LR Chi^2	30.53 (0.0101)	

Source: Authors survey

Notes:
1. The figures in parentheses are standard errors of the coefficients.
2. * Significant at 5% level.
   ** Significant at 10% level.
3. The reference sector is *Electronic Devices and Engineering*
4. There are 38 left-censored observations at a value of zero.

In relation to interaction, only interaction with customers has a significant positive association with innovation intensity. The estimated coefficient indicates that those businesses that interacted with customers for innovation had more new products per 100 employees. None of the estimated coefficients for the other interaction variables are significant. Clearly, compared to the effect on the likelihood of innovation (presented in Table 6.4), interaction is less important with regard to the intensity of product innovation. Roper (2001) also finds this result. Citing Brouwer and Kleinknecht (1996), he suggests that interaction with other businesses may help businesses to overcome obstacles to becoming a product innovator, but that it may not be important in increasing the intensity of product innovation activity subsequently (Roper, 2001:224). This is only true in relation to interaction with agents other than customers. Customers remain important interaction agents, and this is consistent with the view expressed by Kline and Rosenberg that successful innovation “must combine design characteristics that will match closely with the needs and tastes of eventual users" (1986:277). Many innovations are incremental improvements to existing products, and these may be stimulated by feedback from customers.

The previous two estimations suggest that interaction with customers, suppliers and innovation-supporting agencies and R&D are important in enabling businesses to become product innovators, though these factors may not increase the scale of innovation or explain a significant amount of the variation in relative innovation across businesses. In regard to the latter, customers emerge as the only significant interaction agents.

A third aspect of product innovation, which is modelled in the next section is the relative success of product innovation.

6.2.3 Tobit Estimation of Product Innovation Success

Table 6.6 presents the results of a tobit estimation of product innovation success. Based on Roper (2001) success in product innovation is measured by the percentage of turnover in 2003 attributable to products newly introduced in the three-year period between 2001 and 2003. Tobit estimation is appropriate as the dependent variable is censored with lower and upper limits at 0% and 100% respectively. The equation is estimated for product innovators only, that is those businesses that indicated they introduced at least one new product in the three-years between 2001 and 2003. Alternative estimations of this model using different indicators for the independent variables are presented in Appendix 10.

Table 6.6 – Tobit Model of Innovation Success (Product Innovators Only)[1]

	Coefficients[2]	Z Statistic[3]
Business Characteristics		
Age	-0.2976	-1.69**
	(0.0177)	
Size	-0.0094	-0.54
	(0.0176)	
Turnover Growth	3.5058	3.92*
	(0.8934)	
Foreign Ownership	-10.9176	-1.17
	(9.3550)	
Workforce Education	0.0145	0.11
	(0.1298)	
Sector[4]		
ICT	3.8406	0.49
	(7.9125)	
Chemicals and Pharmaceuticals	-9.7290	-1.30
	(7.5077)	
Research and Development		
R&D Department	-2.7994	-0.39
	(7.2146)	
R&D Expenditure		
<5%	-5.7738	-0.70
	(8.1976)	
6-10%	-1.8598	-0.17
	(10.7503)	
>10%	26.5959	2.20*
	(12.0821)	
Interaction		
Interaction Score	2.4129	2.50*
	(0.9638)	
Group Member	23.0395	2.39*
	(9.6337)	

Table 6.6 continued – Tobit Model of Innovation Success (Product Innovators Only)[1]		
	Coefficients[2]	Z Statistic[3]
Constant	-19.8077 (15.9418)	-1.24
N	143[5]	
Log Likelihood	-583.6165	
Pseudo R2	0.0670	
LR Chi2	83.82 (0.0000)	

Source: Authors survey

Notes:
1. The equation is estimated with upper and lower censoring at 0 and 100%.
2. The figures in parentheses are standard errors of the coefficients.
3. * Significant at 5% level.
   ** Significant at 10% level.
4. The reference sector is *Electronic Devices and Engineering*
5. There are 6 left-censored observations at a value of zero and 23 right-censored observations at a value of 100%.

The first significant result of this Tobit estimation is the estimated coefficient for business age which indicates that older businesses tend to have a smaller proportion of turnover attributable to new products. A one year increase in age reduces the proportion of turnover from new products by 0.30%. This may be explained by older businesses having more established and mature products in the market, while new businesses by their nature are more likely to have newer products.

Higher growth in turnover has a significantly positive effect on product innovation success. A one unit increase in the rate of turnover growth increases the proportion of turnover attributable to new products by just over 3.5%.

The results show that R&D effort and interaction for innovation are positively associated with innovation success. The estimated coefficient for spending more than

10% of turnover on R&D is significantly positive. Relative to no R&D expenditure spending more than 10% on R&D increases the percentage of turnover due to new products by 26.7%. The estimated coefficients for lower levels of spending on R&D are not significant, which suggests that there is a threshold level of R&D expenditure above which product innovation success is positively affected.

Interaction also has a significant and positive effect on the level of product innovation success. A one unit increase in the interaction score variable, which measures the diversity of interaction across all agents and is described in Section 6.1.2.3, increases the percentage of turnover from new products by 2.4%. This is a sizeable effect, since the interaction score variable ranges from 5 to 25. The group membership variable, which is a proxy for the incidence of intra-group interaction, has a very sizeable and significant positive effect on product innovation success. Those businesses that are members of a larger group of companies have just under 23% more of their turnover attributable to new products than stand-alone businesses.

The models presented here indicate that R&D effort and interaction for innovation both increase the likelihood of product innovation and (for interaction with customers) the intensity of that innovation. Moreover, for product innovators, higher spending on R&D and greater levels of interaction are associated with greater innovation success, as measured by the percentage of turnover attributable to new products.

6.2.4 Summary Results for Product Innovation

The estimation results presented above indicate that R&D and interaction are important drivers of product innovation in Ireland's high-technology businesses. Businesses that performed R&D are more likely, by a factor of 3.25, to be product innovators than those that did not perform R&D. Also, higher levels of R&D expenditure are associated with more innovation success. Relative to no R&D spending, businesses that spent more than 10% of their turnover on R&D had 26.7% more of their turnover attributable to new products. None of the estimations show a significant relationship between a dedicated R&D department and product innovation output. This indicates that R&D does not necessarily have to be formalised within an innovating business to be effective in driving product innovation.

The results also provide evidence that interaction is another key source of knowledge for product innovation. More frequent interaction with suppliers, customers and innovation-supporting agencies significantly increase the odds of being a product innovator (by a factor of 1.52, 1.77 and 2.31 respectively). Notably, a significant negative relationship is found between the frequency of interaction with academic-based researchers and the probability of introducing new products. Suppliers are found to be the only interaction agent with whom interaction increases the intensity of product innovation. This suggests that, while interaction increases the chances of product innovation, it does not increase the scale of product innovation. Interaction also has a significantly positive effect on the success of product innovation.

6.3 Estimating the Innovation Production Function for Process Innovation

This section reports similar analysis for process innovation to those reported above for product innovation. Two indicators of process innovation are available from the survey data. The first is the incidence of process innovation, whether or not a business introduced a new process in the three-year period between 2001 and 2003, and the second is the frequency of process innovation over the same period. This section reports a logit estimation of the probability of process innovation and an ordered probit estimation of the frequency of introducing new processes.

6.3.1 Logit Estimation of the Probability of Regular Process Innovation

In Chapter 5 it was noted that 98% of respondents indicated that they are process innovators, in that they introduced new processes at least rarely in the three-year period between 2001 and 2003. Adopting a similar binary variable to that used in product innovation (whether the business is a product innovator or not) would provide such little variability that it could not be used as a process output indicator. Since respondents are asked to indicate the frequency with which they introduced process innovations on a five point scale from never to rarely, regularly, frequently to continuously, it is possible to identify a point at which sufficient variability occurs to facilitate the use of a binary output indicator. The analysis that follows estimates the likelihood that a business introduces new processes on at least a regular basis. In this case the dependent variable takes a value of 1 if the business introduced new processes on a regular, frequent or continuous basis and a value of 0 if new processes are not introduced at all or rarely. Table 6.7 presents a logit estimation of the probability of being a regular process innovator. Alternative estimations of the probability of introducing process innovation on at least a regular basis are reported in Appendix 11. The estimation presented in Table 6.7 has the strongest explanatory power.

Table 6.7 – Logit Model of the Probability of Introducing Process Innovation on at Least a Regular Basis

	Coefficients[1]	Z Statistic[2]	Weighted Elasticities
Business Characteristics			
Age	-0.0280	-2.09*	-0.0055
	(0.0134)		
Size	0.0044	1.69**	0.0268
	(0.0026)		
Turnover Growth	0.0653	0.93	0.0095
	(0.0700)		
Foreign Ownership	0.3530	0.42	0.0063
	(0.8341)		
Workforce Education	-0.0017	-0.19	-0.0031
	(0.0086)		
Sector[3]			
ICT	-0.1238	-0.22	-0.0008
	(0.0575)		
Chemicals and Pharmaceuticals	-0.1773	-0.31	-0.0019
	(0.5687)		
Research and Development			
Perform R&D	2.4175	3.56*	0.1589
	(0.6784)		
R&D Department	-0.8182	-1.29	-0.0340
	(0.6352)		
Frequency of Interaction			
Supplier	0.5831	2.74*	0.0744
	(0.2128)		
Customer	0.3934	2.21*	0.0637
	(0.1780)		
Competitor	-0.1108	-0.37	-0.0054
	(0.2970)		

Table 6.7 continued – Logit Model of the Probability of Introducing Process Innovation on at Least a Regular Basis			
	Coefficients[1]	Z Statistic[2]	Weighted Elasticities
Academic	-0.6700 (0.3113)	-2.15*	-0.0540
Agency	0.4271 (0.3218)	1.33	0.0472
Group Member	-0.1720 (0.8085)	-0.21	-0.0047
Constant	-2.4507 (0.9462)	-2.58*	
N	170		
Log Likelihood	-70.9730		
Pseudo R2	0.2699		
LR Chi2	52.47 (0.0000)		
Percentage Correctly Predicted			
Overall	81.8%		
Innovator	84.7%		
Non-Innovator	69.7%		

Source: Authors survey

Notes:
1. The figures in parentheses are standard errors of the coefficients.
2. * Significant at 5% level.
   ** Significant at 10% level.
3. The reference sector is *Electronic Devices and Engineering*.

With regard to the business specific characteristics, business age and size have significant estimated coefficients. The sign of the estimated coefficient for business age is negative. A one year increase in age reduces the log odds of regular process innovation by 0.028. This, together with the finding of a positive coefficient for product innovation (see Table 6.4), implies that older businesses tend to be more likely to be product innovators and less likely to be process innovators. This may suggest that older businesses tend to have well-established routines and processes, making them slower and more difficult to introduce new processes. Unlike product innovation, business size does not have a significant association with the probability of introducing new processes on a regular basis.

The size of the business has a positive effect on the probability of regular process innovation. No size effect was found in relation to the incidence of product innovation. The positive estimated coefficient reported in Table 6.7 indicates that larger businesses tend to have a greater probability of introducing process innovation on at least a regular basis. This is consistent with Freel (2004), though the effect is relatively small in Table 6.7. The weighted elasticity of 0.0268, which means a 1% increase in the number of employees increases the probability of regular process innovation by 2.68%, is relatively small relative to other significant variables.

As was seen earlier in relation to product innovation, workforce education, measured as the percentage of the workforce with a third-level or equivalent qualification is an indicator of absorptive capacity within a business. As discussed in Chapter 2, absorptive capacity is the ability of workers within a business to recognise, evaluate and exploit external knowledge (Cohen and Levinthal, 1990). While interaction emerges as a significant effect on innovation, which is considered later in this section, it is notable that a greater percentage of graduates in the workforce does not increase the probability of product innovation. This of course does not mean that absorptive capacity is not present, but may instead indicate that third-level qualifications may not provide the types of skills needed for identifying exploitable external knowledge, which may instead be developed through 'on-the-job' experience.

While businesses in the *Chemicals and Pharmaceuticals* sector are reported to be less likely to be product innovators than the reference sector, *Engineering and Electronic Devices*, there is no evidence of a variation across sectors for regular process innovation. The variables in relation to turnover growth and ownership are also insignificant. This indicates that higher rates of turnover growth are not associated with a greater probability of regular process innovation and there is no evidence of a difference in regular process innovation between indigenous and foreign-owned businesses.

Just as with product innovation, R&D and interaction emerge as having significant effects on the likelihood of being a regular process innovator. Performing R&D has a large and significant effect on the odds of introducing process innovations on a regular basis. Where a business performs R&D the logged odds of being a regular process innovator is greater by a factor of 2.4175, which means that R&D increases the odds of regular process innovation by a factor of 11.21. The weighted elasticity of the R&D binary variable is also large relative to the other significant variables. Performing R&D increases the probability of being a regular process innovator by 15.89% relative to those businesses that do not perform R&D. There is no significant relationship between the likelihood of regular process innovation and the existence of a dedicated R&D department.

Higher frequencies of interaction with suppliers and customers are also associated with a greater likelihood of regular process innovation, just as they are with product innovation. The estimated coefficients for both variables are significant. According to the weighted elasticities, a one unit increase in the frequency of interaction with suppliers increases the probability of regular process innovation by a 7.5% and a one unit increase in the frequency of customer interaction increases the probability by 6.37%. The relative importance of these two interaction agents is reversed relative to the results reported for product innovation. This indicates that while forward linkages are important to enable businesses to learn of market opportunities for new products through customer interaction, interaction with suppliers is more important for process innovation, which suggests that new processes may be tied to the adoption of new sources of supply or new equipment.

The notable negative association between interaction with academic-based researchers and innovation output that is observed for product innovation is also evident for process innovation. A one unit increase in the frequency of interaction with academic-based researchers reduces the probability of introducing new processes on at least a regular basis by 5.4%. Just as with product innovation, this may reflect a tendency for businesses to access academic-based researchers where innovation is more complex or difficult. Interaction with innovation-supporting agencies is not significant for process innovation, unlike product innovation. Perhaps this reflects an emphasis on product innovation among the innovation-supporting agencies. Once again, interaction with competitors is not seen as a significant effects on the likelihood of innovation.

Overall, the model is significant. The p-value for the likelihood ratio (LR) X^2 is less than 0.05 so the hypothesis that there is no difference between the estimated model and the constant only model can be rejected. The estimation reported in Table 6.7 has the greatest explanatory power relative to alternative estimations based on the same criteria used for the logit estimation of the probability of product innovation.

6.3.2 Ordered Probit Estimation of Process Innovation Frequency

In this study process innovation is measured as the frequency of the introduction of new processes. This frequency is measured on a five point scale from never to rarely, regularly, frequently to continuously. This is the first study to use this measure of process innovation. This section presents an ordered probit model of the probability of introducing new processes at each level of frequency. An ordered probit model is used since the dependent variable (process innovation frequency) is a discrete and ordered variable (Dahlgren, 2005).

Table 6.8 presents the results of an ordered probit estimation. The ordered probit technique estimates multiple equations, each with the same coefficients. This is known as a proportional odds model.

Table 6.8 – Ordered Probit Model of the Frequency of Introduction of New Processes

	Coefficients[1]	Z Statistic[2]
Business Characteristics		
Age	-0.0102	-1.90**
	(0.0054)	
Size	0.0011	1.84**
	(0.0006)	
Turnover Growth	0.0245	0.93
	(0.0264)	
Foreign Ownership	0.0990	0.34
	(0.2949)	
Workforce Education	-0.0012	-0.36
	0.0033	
Sector[3]		
ICT	-0.0534	-0.25
	(0.2167)	
Chemicals and Pharmaceuticals	-0.3310	-1.50
	(0.2211)	
Research and Development		
Perform R&D	0.7089	3.02*
	(0.2350)	
R&D Department	-0.1328	-0.62
	(0.2156)	
Interaction		
Interaction Score	0.0825	3.55*
	(0.0233)	
Group Member	0.2078	0.70
	(0.2949)	
Cut 1	-0.8747	
	(0.3927)	
Cut 2	0.6420	
	(0.3591)	
Cut 3	1.6002	
	(0.3696)	
Cut 4	2.0496	
	(0.3761)	
N	178	
Log Likelihood	-232.548	
Pseudo R2	0.0844	
LR Chi2	42.86	
	(0.0000)	

Source: Authors survey

Notes: 1. The figures in parentheses are standard errors of the coefficients.
2. * Significant at 5% level.
** Significant at 10% level.
3. The reference sector is *Electronic Devices and Engineering*

Just as with the logit estimation of the likelihood of regular process innovation, age has a significant negative effect on the frequency of process innovation. Older businesses are likely to introduce process innovations less frequently. The size of the business has a significant and positive estimated coefficient, indicating that larger businesses have a greater probability of more frequent process innovation than smaller businesses. These are the only business characteristics variables that are have significant effects on the frequency of process innovation. The frequency of process innovation appears to be independent of the sector in which the business operates and whether the business is Irish or foreign-owned. Once again, the percentage of the workforce with third-level or equivalent qualifications does not significantly affect process innovation frequency.

Performing R&D has a significant positive effect on the frequency of process innovation, just as it had on the likelihood of introducing process innovation on a regular basis. This is also in line with the findings on the probability of product innovation. Once again, the presence of a dedicated R&D function has no significant effect.

The interaction variable that has greatest explanatory power in relation to the frequency of process innovation is the aggregate interaction score. This indicator, discussed in more detail in section 6., ranges in value from 5 (representing no interaction with any interaction agent) to 25 (representing continuous interaction with all interaction agents) and is a measure of the diversity of interaction for innovation. The interaction score variable has a significant positive effect on the frequency of process innovation. This indicates that more frequent interaction with a broader range of interaction agents increases the frequency of process innovation. While Jacobs (1969) and Glaeser et al (1992) are writing in the context of knowledge spillovers within cities, they argue that diversity is important for knowledge creation. While the model estimated in Table 6.8 is not concerned with spatial aspects of interaction, it does indicate that greater diversity in interaction for innovation increases the frequency of process innovation.

6.3.3 Summary Results for Process Innovation

Just as with product innovation, the estimation results reported in Tables 6.9 and 6.10 indicate that R&D and interaction are important drivers of process innovation in Ireland's high-technology businesses. However, as indicated by the weighted elasticities of the estimated coefficients, R&D is the most important predictor of the probability of regular process innovation. Interaction with suppliers, customers and innovation-supporting agencies had stronger effects on product innovation.

Interaction with suppliers and customers are significantly predictors of the probability of regular process innovation, though their relative importance is reversed relative to the results for product innovation. As noted previously this indicates that process innovation may be based on the introduction of new sources of supply or new equipment.

The negative association between interaction with academic-based researchers and innovation output that is observed for product innovation is also evident for process innovation. This particularly notable finding has important policy implications, which are discussed in detail in the next section.

6.4 Summary of Results and Policy Implications

The results reported in this Chapter indicate that both R&D and interaction for innovation are positively and significantly associated with higher levels of product and process innovation in Ireland's high-technology businesses. They are positively associated with the probability of product and process innovation occurring, with the higher levels of product innovation intensity, with more successful product innovation and with greater frequency of process innovation.

The primary objective of the analysis reported in this Chapter is to shed light on the relative importance of the factors driving innovation in Irish high-technology businesses. Based on the weighted elasticities of the estimated coefficients, interaction with other businesses and organisations is a more important predictor of the probability of product innovation than R&D. In order of magnitude of the weighted elasticities, the probability of product innovation is positively associated with the frequency of interaction with customers, suppliers, innovation-supporting agencies, whether the business performed R&D and the age of business. Performing R&D is the most important predictor of the probability of regular process innovation, followed by the frequency of interaction with suppliers and customers.

Interaction between businesses and other organisations have been identified for some time by policy makers as an important element in supporting business-level innovation, particularly regional and local networks based on clusters (Culliton, 1992; Forfás, 2003 and 2004a; ESG, 2004). While the analysis reported in this Chapter is not concerned with the spatial aspect of interaction, the results provide support for the policy emphasis on the promotion of interaction among businesses to encourage innovation. This study's findings show that interaction among businesses and/or between businesses and innovation-supporting agencies is a significant source of knowledge for innovation in Ireland's high-technology sectors.

Interaction with customers and suppliers is positively associated with the probability of being a product innovator and a regular process innovator. Interaction with customers also increases innovation intensity and higher levels of interaction with the range of agents increases the success of product innovation.

Interaction with customers is more important for product innovation, suggesting that businesses learn of market opportunities for new products through customer interaction. On the other hand, interaction with suppliers is more important for process innovation, which suggests that new processes may be tied to the adoption of new sources of supply or new equipment.

There is no evidence that interaction with competitors positively affects product or process innovation. Interaction with competitors has been an important aspect of the celebrated examples of successful clusters, such as Silicon Valley, Emiglia-Romagna and Cambridge (Scott, 1988, Saxenian, 1990 and Castells and Hall, 1994), on which much of Irish innovation and regional policy draws (for example, Department of the Environment and Local Government, 2002:40; National Competitiveness Council, 2004:3). In these cases businesses are small and flexible, thus enabling alliances to form easily. This study questions whether this aspect of these examples may be replicated in an Irish context. The lack of interaction between competitors in high-technology sectors in Ireland may reflect the particular features of the Irish economy. Typically high-technology businesses located in the country are a mix of very large foreign-owned and smaller indigenous businesses, operating in particular international market niches, with few competing with each other. This prompts consideration of the type of clusters which might reasonably be expected in an Irish context. This is discussed in greater detail when spatial aspects of interaction are explored in Chapter 7.

The study finds a negative relationship between the probability of product and process innovation and the frequency of interaction with academic-based researchers. This result suggests that more frequent interaction with academic-based researchers reduces a business' odds of being an innovator. This is a particularly notable and worrying finding for Irish policy makers, especially in light of the sizeable public investment to date in third-level research and the Irish government's recent commitment to substantial public funding of R&D in coming years (Department of Enterprise, Trade and Employment, 2006). If, as this study indicates, high-technology businesses interact only weakly with academic-based researchers and that interaction decreases the probability of innovation, the question arises as to whether the return to Ireland from this public investment is likely to be satisfactory. Two possible explanations for this finding are discussed earlier in the Chapter. First, businesses and academic-based researchers may have different objectives, with businesses more focused on commercial application of knowledge. For example, Evaltec (2004) contend that business concerns regarding intellectual property is a factor hindering interaction with Irish third-level institutions, who regard intellectual property as an income stream in a way which, in the light of US examples, seems unrealistic. Second, collaboration with academic-based researchers may involve more complex or cutting-edge knowledge, which may be less amenable to commercial application by its nature and so less likely to produce new products or processes.

As discussed in Chapter 2, there is some international evidence of positive spillovers from university research to businesses innovation (Jaffe, 1989; Audretsch and Stephan, 1996, Anselin, Varga and Acs, 2000). However, the extent to which businesses regionally or nationally can benefit from research in third-level institutions depends on factors such as the relevance of the research to businesses, businesses' absorptive capacity, the strength of local knowledge dissemination networks and the integration of public and private knowledge mediating institutions (Roper, Hewitt-Dundas and Love, 2003: 114). The survey finding of weak interaction between high-technology businesses and both academic-based researchers and innovation supporting agencies, casts doubt on the existing strength of Irish regional innovation systems.

These findings may reflect an over-emphasis on the public funding of basic research. O'Leary (2006) presents a survey of assessments of policy interventions concerned with improving linkages between business and academic-based researchers. Forfás (2005b) argue there is a need to fund more applied rather than basic research, to focus on niche areas in a country as small as Ireland and to pay more attention to commercializing research. Technopolis (2004) note that the Innovation Partnerships programme administered by Enterprise Ireland does not involve real partnership as businesses pay for but do not participate in projects. They contend the programme seems to benefit academics more than businesses. While the greater emphasis placed by the Enterprise Strategy Group (ESG) on the funding of applied research and in-company R&D (2004:69) indicates some cognizance of this problem, the recent *Strategy for Science, Technology and Innovation* (Department of Enterprise Trade and Employment, 2006) indicates that public funding is still directed more towards basic research in third-level institutions.

The final interaction agent considered is innovation-supporting agencies, which is found to be significantly positively associated with the probability of product and process innovation. The finding in Chapter 5 that most interaction with suppliers and customers occurs over further distances, and probably internationally in many cases, may explain the positive effect of interaction with innovation-supporting agencies for innovation in Irish high-technology businesses, as it may reflect the role, for example, of Enterprise Ireland in assisting the development of links between Irish businesses and international customers.

Turning to the effect of R&D on business-level innovation, the results indicate that high-technology businesses that perform R&D are more likely to be product innovators and regular process innovators. Also, businesses that spend more than 10% of turnover on R&D have a higher proportion of turnover attributable to newly introduced products. This provides support to interventions from policy-makers to raise both the number of businesses engaged in R&D and the level of R&D in high-technology businesses. The recently published *Strategy for Science, Technology and Innovation* identified a number of measures to support in-company R&D, including simplification and rationalisation of R&D grant structures and extending the R&D tax credit scheme (Department of Enterprise Trade and Employment, 2006:49).

The results suggest however that whether a business performs R&D increases its probability of being a product innovator, but does not statistically affect product innovation intensity, as measured by the number of new products introduced per 100 employees. This suggests that R&D policy may be better aimed at encouraging first-time R&D performers, as recommended in Forfás (2000), rather than supporting incremental R&D expenditure. In this context, the R&D tax credit scheme may need to be reviewed. The tax credit is structured as an incremental scheme operating on a rolling base point, which means that from the base point, the increase in a business's R&D investment for each of the following 3 years is eligible for tax relief. For example, in 2007, the credit is available for the incremental spend over the base point of what the business spent in 2004, and so on. Department of Enterprise Trade and Employment (2006) recognises that the scheme may need to be reviewed in light of the schemes in some other EU countries which operate a volume based R & D tax credit scheme under which the total amount spent on R&D in each year, rather than the increase on a base year, is eligible for the tax relief. A volume based scheme would appear more favourable to smaller businesses engaging in R&D for the first time.

Also, the results do not provide any evidence that the existence of a dedicated R&D department increases the probability of innovation or the intensity of product innovation. This suggests that policy interventions ought to be flexible in supporting R&D that is not formalised or routine. Where financial assistance for in-company R&D is linked to the establishment of dedicated R&D structures it may not increase the probability of businesses introducing new or improved products and processes. It is more likely that exploratory or basic research undertaken in-company may be performed in dedicated R&D facilities, which can support this type of work. The results suggest that publicly funded financial assistance for in-company R&D must encourage applied and less formal R&D activities may be, at least, as important in stimulating business innovation as assistance for large-scale R&D facilities.

It is clear from the analyses presented in this Chapter that external interaction affects the level of innovation in Irish high-technology businesses. This raises the issue of whether the frequency of interaction is affected by spatial distance. There is broad theoretical support for a positive relationship between geographic proximity and knowledge spillovers through interaction. Chapter 7 is focused on the spatial dispersion of interaction for innovation in high-technology businesses and reports an estimation of the factors, including geographic distance, that determine the frequency of interaction with each interaction agent. The Chapter also contains an analysis of the evidence for an urban-hierarchy effect on innovation in high-technology businesses. This analysis estimates, using additional secondary data, the relative importance for innovation of a business' location with a geographic concentration of economic activity. The policy implications of these analyses are discussed at the end of the Chapter.

CHAPTER 7: THE IMPORTANCE OF GEOGRAPHIC PROXIMITY FOR INTERACTION

In the analyses presented in the previous two Chapters there is a statistically significant relationship between interaction and innovation in Irish high-technology businesses. The basis for a role for interaction as a source of innovation is knowledge spillovers. That is, through interaction individuals learn and generate new knowledge. Von Hippel (1988) and Lundvall (1988) state that innovation may occur as a result of interaction between the users of knowledge/innovation and the producers of that knowledge/innovation. Lundvall stresses the social nature of learning and contends that users of innovation must interact with producers in order to become aware of new technologies, understand their potential usefulness and develop know-how in relation to these technologies (1992:59). The theoretical bases for knowledge spillovers have been discussed in detail in Chapter 2 and empirical work on the effect on innovation of interaction is presented in Chapter 3.

The importance of interaction as a source of knowledge for innovation prompts the question of what encourages interaction between users and producers of knowledge and in particular whether geographic proximity and/or agglomeration produces more frequent interaction and, in turn, more innovation. There is a wide literature suggesting that knowledge spillovers are a factor explaining geographic agglomeration of economic and innovative activity (Marshall, 1920; Porter, 1990; Krugman, 1998). Businesses and institutions that are spatially concentrated may be better able to benefit from knowledge spilling over. Glaesar memorably expressed the idea that knowledge spillovers may be more likely to occur over shorter geographical distances when he said “intellectual breakthroughs must cross hallways and streets more easily than oceans and continents” (1992:1127).

This Chapter addresses the issues of proximity and agglomeration, and their effects on interaction for innovation in Ireland’s high-technology businesses. This issue has important policy implications, since Irish policy makers have, in policy statements and interventions, accepted that distance matters for stimulating innovation within businesses. The Department of Enterprise, Trade and Employment state that “centres formed by clusters of internationally recognised researchers from the third-level sector and industry” (2003:124) are a priority for the stimulation of innovation within business. For example, the Digital Hub in Dublin was established in 2003 to develop a cluster of businesses engaged in the digital media products and services. This project is located in the Liberties area of Dublin and businesses are encouraged to locate within the dedicated area and buildings provided by the Digital Hub Development Agency. As well as providing adequate communications infrastructure, businesses are encouraged to cluster, since they “will be close to a supplier and consumer of [their] products and services...networking and collaborating are supported…and there is a vibrant social scene” (Digital Hub Development Agency, 2006).

Irish regional policy also suggests an important role for clusters. The National Spatial Strategy (NSS) argues that regional imbalances can be addressed through the development of regional gateways which are “large clusters of national/international scale enterprises, including those involved in advanced sectors" (Department of Environment and Local Government, 2002:40).

The analysis reported in this Chapter sheds light on the relative impact of geographic proximity on the frequency of interaction and the effect of agglomeration on innovation in Irish high-technology businesses. The Chapter is presented as follows. First, based on Freel (2003), discriminant analysis is presented based on the geographic distance between businesses and customers and businesses and suppliers with which they have interacted for product and process innovation. This section reports discriminant analysis based on proximity to customers and suppliers only since it is reported in Sections 5.4 and 5.5 that interaction with these two interaction agents is much more frequent than with others and these two agents were also reported in Tables 6.4 and 6.5 to be significantly positively associated with a higher probability of product and process innovation. The effect of geographic proximity on interaction with all of the other agents is considered in subsequent sections. The discriminant analysis in Section 7.1 explores differences in the level of innovation, interaction with customers and suppliers for innovation and R&D across a range of geographic distances. This is done to examine whether geographical proximity between high-technology businesses and the customers and suppliers with which they interact for innovation is associated with higher levels of product and process innovation.

While the first section presents a descriptive analysis of the relationship between proximity and interaction, the second section reports inferential analysis of the factors that drive interaction for innovation in high-technology businesses. A model of interaction for innovation is presented and estimated. Ordered probit estimations of the frequency of interaction with each interaction agent are reported, including geographic proximity to the relevant interaction agent as a dependent variable. This approach sheds light on the factors that determine whether a high-technology business engages in interaction for innovation, and in particular whether proximity increases the frequency of interaction.

In the third section, the effect of agglomeration on innovation in Irish high-technology businesses is examined. Agglomeration economies, which are discussed in detail in Section 2.5.1, may take the form of localisation or urbanisation economies (Parr, 2002). The former are derived from the common location of businesses in the same industry, and are based on the ability to share intermediate inputs, access to a thick skilled labour market and knowledge spillovers. Knowledge spillovers arise through interaction between businesses and movement of labour among businesses within the agglomeration. Urbanisation economies arise from the common location of businesses belonging to different and unrelated industries, which is typically seen in an urban area. In relation to innovation, the benefits of an urban location may be greater scope for interaction for innovation with a more diverse range of interaction agents. First, the urban environment provides a greater variety of skills and knowledge unavailable in more rural locations and urban cultures tend to be more permissive and open to new ideas, products and processes. Second, urban areas are typically characterised by greater levels of competition for local customers, which may act to stimulate innovation among businesses located in the urban area. Finally, geographic concentration of economic activity may be associated with better transport and communications infrastructure, which facilitates more frequent interaction between businesses in the region. Also, communications and transport infrastructure may make interaction with more distant businesses easier. For example, broadband availability or the existence of an international airport improves accessibility to potential interaction agents outside the local area or abroad.

Regional or local interaction with suppliers, customers and competitors, which are businesses in the same or related industries and is measured in the survey of high-technology businesses, is an indicator of the knowledge spillovers element of localisation economies. The analysis reported in Tables 5.29 and 5.36 provides little evidence that Irish high-technology businesses are interacting locally or regionally for innovation. It is necessary to use secondary data to estimate the effect of the other element of localisation economies which refers to the thickness of local skilled labour markets. Indicators of urbanisation economies are based on secondary data on population density, distance from the nearest major airport, the proportion of science-based graduates, the proportion of professional and technical workers and whether a business is located in a hub or gateway as defined in the NSS (Department of the Environment and Local Government, 2002).

In the final section of this Chapter, the policy implications of the analyses presented in this Chapter are considered.

7.1 Discriminant Analysis of the Effect of Distance on Innovation Activity

Discriminant analysis is used to classify cases into the values of a categorical dependent variable, which in this case is the geographical distance between a high-technology business and customers and suppliers with which they interact for product and process innovation. Geographical distance is measured using the average one-way driving time to the interaction agent in question. The justification for this measure is set out in section 4.4. While the survey data categorises driving times into five intervals, for the purpose of these discriminant analyses driving times are grouped into three categories, less than one hour, one to four hours and greater than 4 hours. This grouping is used to ensure sufficient observations within each category. The analysis reported in this section relates only to customer and supplier interaction since these agents emerged as significant and important determinants of the likelihood of product and regular process innovation in the innovation models estimated in Chapter 6.

The discriminant analyses presented in Tables 7.1 to 7.4 relate to the geographic distance between businesses and customers and suppliers with which they have interacted for product and process innovation. Freel (2003) adopts a similar methodology using the highest spatial level of innovation-related links as the categorizing variable. The spatial categories are local, regional, national and international. The analysis presented here differs from Freel (2003) by considering the spatial dispersion of specific interaction agents. The independent variables chosen for this analysis are based on those in Freel's (2003) study. Appendix 12 contains a technical note on the discriminant analysis technique adopted here.

7.1.1 Interaction with Customers for Product Innovation

Table 7.1 reports the results of a discriminant analysis using the distance to customers with which interaction for product innovation has taken place as the dependent variable. There are no observations for proximity to customers where interaction with customers has not taken place. The table contains the predictor or dependent variables and the correlations between these predictor variables and the discriminant functions. The dependent variables correspond to those reported in Freel (2003) as being associated with the spatial distribution of interaction for innovation. Freel notes that interpretation of these correlations follows a rule of thumb that only correlations in excess of 0.33 may be considered eligible for interpretation (2003:764) and this convention is also adopted here. Table 7.1 also reports a Wilks' lambda test of the significance of the discriminant functions as a whole. A significant lambda means the null hypothesis that the groups have the same mean discriminant function can be rejected and indicates that the model is discriminating. Finally, in Table 7.1 the means, or in the case of binary variables the proportions, of each independent or predictor variable for each category of the dependent variable are reported. Subsequent tables report the same statistics.

Table 7.1 – Discriminant functions of the spatial distribution of customers that interact for product innovation

Predictor Variables	Correlations of predictor variables with discriminant functions			
	1	2	Univariate F(2,150)	
Size	0.244	0.007	0.853	
Employee Education Levels	0.353	0.970	2.738 *	
Perform RD	0.646	-0.480	6.714 ***	
Foreign Ownership	0.346	0.602	1.112	
Product Innovator	0.456	-0.007	3.495 **	
Frequency of Customer Interaction	-0.122	-0.359	0.744	
Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 2	0.838	26.087	12	0.010
2	0.945	8.337	5	0.139
	Group Means and proportions			
	<1 hour	1 to 4 hours	>4 hours	
Size	96.13	84.05	130.74	
Employee Education Levels	44.70	33.12	48.08	
Perform RD	0.48	0.63	0.82	
Foreign Ownership	0.52	0.34	0.45	
Product Innovator	0.70	0.78	0.90	
Frequency of Customer Interaction	4.09	4.20	4.31	
N	23	41	89	

Source: Author's survey

Notes: *** Significant at 1% level
** Significant at 5% level
* Significant at 10% level

In Table 7.1 the two functions generated are found to be effective predictors of category membership [Chi-Square=26.08, df=12, p=0.010]. The size of the business, measured as the number of employees, does not significantly differ across the three distance categories. *A priori* it might be expected that larger businesses are more likely to interact with closer customers, as these customers, which may be smaller, are attracted to locate close to the larger business. However, in Table 5.5 in Chapter 5 it is reported that foreign-owned businesses are significantly larger than indigenous businesses. Foreign-owned businesses may have more international customers and this may offset the effect of larger businesses attracting smaller customers to locate closer to them. In Table 7.1 the proportion of foreign businesses does not differ significantly across the distance categories, though a slightly higher proportion of foreign businesses interact with customers located less than one hour drive away.

Businesses that perform R&D tend to interact with customers over greater distances. 82% of businesses that interacted with customers located more than 4 hours drive away performed R&D. This compares with just under half of businesses that interacted with local customers (less than 1 hours drive away). That this analysis is based on high-technology businesses may explain why this finding differs from Freel, who finds R&D, measured by the level of expenditure, does not affect the spatial distribution of innovation-related links (2003:765). There may be two potential explanations for this finding. First, businesses engaged in R&D may be more likely to interact with sophisticated customers, perhaps also engaged in the R&D, and this may be more important than geographic location. Alternatively, those businesses that do not engage in R&D may be more likely to source the knowledge for innovation from interaction with customers and may need to locate close to customers where there is an absence of R&D. In this situation interaction with customers for innovation may be considered a substitute for performing R&D.

It is also notable that a greater proportion of businesses that interact with customers over longer distances are product innovators. 90% of businesses that identified their most important customer for product innovation as being located more than 4 hours drive away are product innovators. This compares with 70% of businesses interacting with customers less than 1 hours drive away. This finding is inconsistent with what might be expected from the regional innovation systems, innovative mileux and clusters literatures. These literatures stress the importance of localised knowledge spillovers and linkages as a driver of innovation.

The level of educational attainment of employees is the only other significant predictor at a 90% confidence level in the discriminant analysis reported in Table 7.1. The proportion of employees with third-level qualifications is significantly lower among businesses that interact with customers between 1 and 4 hours drive away. There is little difference between the two extreme categories. Therefore, there seems to be an ambiguous relationship between employees' education levels and the geographical distance to customers with which interaction takes place.

It is notable that the frequency with which businesses interact with customers does not differ significantly between the three proximity groups, suggesting that frequency is independent of distance. This is inconsistent with the important role of spatially bounded interaction within regional innovation models and clusters. These frameworks suggest that geographic proximity facilitates easier, and as a consequence more frequent, interaction, increasing the spillover of tacit knowledge. For Irish high-technology businesses there is no significant difference in the frequency of interaction with customers across the range of spatial categories. In fact, while the difference in means across the groups is insignificant, the mean frequency of interaction increases slightly as geographical distance increases.

7.1.2 Interaction with Suppliers for Product Innovation

Table 7.2 reports the results of a multiple discriminant analysis using proximity to suppliers with whom businesses interact for product innovation as the grouping variable. The two functions generated are effective predictors of category membership [Chi-Square=25.465, df=12, p=0.013].

The results in Table 7.2 show that larger businesses tend to interact for product innovation with suppliers over greater geographic distances. The businesses that interact with local (less than 1 hours drive) suppliers are less than half the size on average of businesses interacting over the greatest geographic distance and almost one quarter of the size of businesses whose most important supplier for product innovation is between 1 and 4 hours drive away. It may be that larger businesses have more scope for identifying a range of suppliers and proximity may be a less important consideration in deciding on suppliers. Also, it was noted in Table 5.5 that foreign-owned businesses in the survey population, which may be expected to have international suppliers to the entire group of businesses, are significantly larger than indigenous businesses. This effect is also evident in the finding in Table 7.2 that there is a significantly larger proportion of foreign businesses among those that interact with suppliers over greater distances, 25% of businesses that interact for product innovation with suppliers less than 1 hour away are foreign-owned compared to 46%

of those businesses interacting over 4 hours drive away and 58% interacting with suppliers between 1 and 4 hours away.

Table 7.2 – Discriminant functions of the spatial distribution of suppliers that interact for product innovation

Predictor variables	Correlations of predictor variables with discriminant functions			
	1	2	Univariate F(2,136)	
Size	0.389	0.192	2.798 *	
Employee Education Levels	-0.308	0.633	2.929 *	
Perform RD	-0.382	0.058	2.788 *	
Foreign Ownership	0.168	0.637	3.432 **	
Product Innovator	-0.325	0.436	2.539 *	
Frequency of Supplier Interaction	0.580	0.193	3.090 **	
Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 2	0.826	25.465	12	0.013
2	0.972	3.755	5	0.585
	Group Means and proportions			
	<1 hour	1 to 4 hours	>4 hours	
Size	46.89	164.70	113.67	
Employee Education Levels	45.21	29.15	45.12	
Perform RD	0.79	0.55	0.74	
Foreign Ownership	0.25	0.58	0.46	
Product Innovator	0.89	0.73	0.88	
Frequency of Supplier Interaction	3.57	4.15	3.90	
n	28	33	78	

Source: Author’s survey

Notes: *** Significant at 1% level
** Significant at 5% level
* Significant at 10% level

In Table 7.1 it is seen that the proportion of businesses that are product innovators increases as the distance to customers increases. However, in the Table 7.2 there is no difference in the proportion of those businesses interacting in the least distant group and in the most distant group that are product innovators. The proportion of product innovators in the interim group (between one and four hours) is significantly lower. This indicates that geographic proximity to suppliers for product innovation interaction does not increase the likelihood of innovation. The pattern described here can also be seen in relation to the proportion of businesses in each geographic group that perform R&D.

In Table 7.2 a significant difference is found between the frequency of interaction for product innovation with suppliers and geographic proximity to those suppliers. However, the pattern that emerges is that the average frequency of interaction is greater with suppliers located between one and four hours and more than four hours drive away than it is with suppliers located geographically proximate. This finding is inconsistent with *a priori* expectations, that proximity facilitates easier and therefore more frequent interaction. This finding is important in that it indicates that not only does proximity not increase the frequency of interaction for innovation, but for these high-technology businesses there is a negative relationship between distance and the frequency of interaction.

7.1.3 Interaction with Customers for Process Innovation

Table 7.3 reports the results of a discriminant analysis using the distance to customers with which interaction for process innovation has taken place as the dependent variable. In Table 7.3 the two functions generated are effective predictors of group membership [Chi-Square=27.469, df=12, p=0.007].

Table 7.3 – Discriminant functions of the spatial distribution of customers that interact for process innovation				
Predictor variables	Correlations of predictor variables with discriminant functions			
	1	2	F(2,124)	
Size	0.061	0.281	0.985	**
Employee Education Levels	0.571	-0.661	3.968	**
Perform RD	0.284	0.801	3.336	***
Foreign Ownership	0.595	-0.108	2.745	
Regular Process Innovator	0.494	-0.103	5.707	*
Frequency of Customer Interaction	-0.160	0.457	0.242	
Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 2	0.798	27.469	12	0.007
2	0.980	2.496	5	0.777
	<1 hour	1 to 4 hours	>4 hours	
Size	89.26	98.50	148.09	
Employee Education Levels	40.04	29.18	48.39	
Perform RD	0.57	0.62	0.80	
Foreign Ownership	0.39	0.29	0.53	
Regular Process Innovator	0.70	0.65	0.90	
Frequency of Customer Interaction	3.57	3.71	3.74	
n	23	34	70	

Source: Author's survey

Notes: *** Significant at 1% level
** Significant at 5% level
* Significant at 10% level

Larger businesses tend to interact for process innovation with customers over greater geographic distances. The businesses that interact with more distant (more than four hours drive) customers are almost 50% larger on average than businesses interacting over shorter distances. This is consistent with the results reported in Table 7.2, though in this case there is no significant difference in the proportion of foreign owned businesses in each distance category.

Similarly to the results for interaction with customers for product innovation reported in Table 7.1, the proportion of employees with third-level qualifications is significantly lower among businesses that interact with customers between one and four hours drive away. Once again there is an ambiguous relationship between employee education levels and geographical distance to customers with which interaction takes place.

As is also seen in Table 7.1 businesses that perform R&D tend to interact with customers over greater distances. The explanations for this result in relation to interaction with customers for product innovation may also be valid here. Businesses engaged in R&D may prefer to interact sophisticated customers, perhaps also engaged in the R&D, irrespective of location and this may be more important than the proximity of customers. Also, businesses not engaged in R&D may locate close to customers to benefit from interaction as a substitute for R&D.

Those businesses that interact with customers over greater distances are more likely to be regular process innovators than those interacting with more proximate customers. This is also found to be the case in relation to product innovators and raises questions about the benefits of geographic or spatially bounded clusters as a stimulus for innovation among Irish high-technology businesses.

Once again, geographic proximity is not found to be a significant predictor of the frequency of interaction for innovation. There is no significant difference between the average levels of interaction frequency between the distance categories.

A discriminant analysis using the distance to suppliers with which interaction for process innovation has taken place as the dependent variable is also performed. However, the two functions generated are not effective predictors of group membership and it is not possible to reject the null hypothesis that the model is not discriminating [Chi-Square=14.481, df=12, p=0.271]. Appendix 13 contains the results of this discriminant analysis, but since the discriminant functions are not significant these are not discussed here.

7.1.4 Summary Results from Discriminant Analysis

The results presented in Tables 7.1 to 7.3 provide no evidence of a positive relationship between the frequency of interaction for innovation and the geographical proximity of the interaction agents. There is no significant difference across the proximity categories with respect to customer interaction for product innovation and process innovation. With respect to interaction for product innovation with suppliers it is found that the average frequency of interaction is significantly higher with suppliers located farther away.

These results raise questions about the importance of geographical proximity for innovation in Irish high-technology businesses. The policy implications of these results are discussed later in the Chapter, though it is clear from this sample of Irish high-technology businesses that these businesses do not operate within typical clusters or regional innovation systems despite attempts by Irish policy-makers to stimulate regional clusters and linkages in these sectors. Efforts to encourage businesses in these high-technology sectors to locate close together to stimulate a networked or innovative environment may be misplaced.

A conclusion from the analysis above is that, for Irish high-technology businesses, interaction for innovation is independent of geographic proximity to interaction agents. This prompts the question what factors affect the level of interaction for innovation in Irish high-technology businesses. This question is addressed in the next section.

7.2 Geographic Proximity and Interaction for Innovation

In this section the determinants of interaction for innovation in Irish high-technology businesses are explored. As discussed in detail in section 2., Kline and Rosenberg, in presenting the chain-link model of innovation, state that "when we confront a problem of technical innovation, we call first on known science, stored knowledge, and we do so in serial stages" (1986:291). This suggests that interaction for innovation occurs as part of a process where a solution to a technical problem cannot be solved internally. It is also the case that interaction for innovation is not cost-free. There is an investment of time and resources in identifying potential interaction partners and establishing a relationship and trust with that partner. Where interaction is market-mediated, perhaps as part of a joint venture, there may be legal or contractual costs in establishing property rights over the outcome of the collaboration. Interaction, even where not market-mediated, involves risk that proprietary knowledge may be lost and efforts to protect this knowledge may involve costs. What this means is that interaction for innovation may result from a deliberate decision by a business, involving a search for interaction partners or putting the business in a position where it can absorb or benefit from knowledge spillovers. Section 2.4 discusses in detail the theoretical basis for the role of interaction as a source of innovation.

As well as geographic proximity, which has been explored in the earlier analyses, other factors may determine whether a business interacts for innovation with a particular interaction agent. These may include whether the business performs R&D, as interaction may be seen as a substitute or a complement to R&D activity. Cohen and Levinthal (1990) argue that businesses may engage in R&D to build absorptive capacity which enables them to better identify, evaluate and exploit external knowledge. Another factor may be whether the business interacts with other interaction agents. Where a business interacts with customers for innovation, it may be more open to interaction with suppliers, competitors or academic-based researchers. This is discussed in more detail in Section 6.2 in the construction of a composite indicator of external interaction. It was noted in that section that there is no basis for believing that any one interaction agent is a more important source of knowledge for innovation than any other and it is not possible to say ex ante from which agent knowledge for innovation will come. It may be that businesses interacting with external agents are less insular in outlook and more likely to interact with others. This idea is tested in the estimations that follow in Sections 7.2.1 and 7.2.2.

This section explores the relationship between interaction and the factors discussed above by modelling interaction as set out in Equation 7.1.

$$N_{ij} = \beta_0 + \beta_1 Z_i + \beta_2 R_i + \beta_3 N_{ik} + \beta_4 P_{ij} + \varepsilon_i \qquad \text{Equation 7.1}$$

where N_{ij} is an indicator of interaction between business i and interaction agent j.
Z_i is a range of business-specific factors that may affect business i's interaction for innovation.
R_i is an indicator of R&D effort in business i.
N_{ik} is an indicator of interaction between business i and interaction agent k, where $k \neq j$.
P_{ij} is an indicator of the geographical proximity between business i and interaction agent j.

This model is estimated below for each interaction agent. In these estimations, interaction between business i and interaction agents j and k, referred to as N_{ij} and N_{jk} in equation 7.1, is measured by the reported frequency of interaction measured on a five-point interval ranging from never to rarely, regularly, frequently to continuously. Since these are ordered responses an ordered probit estimation is used. This is the most common way to deal with such dependent variables (Davidson and MacKinnon, 1993:529). An ordered probit model is used earlier in this thesis to model the frequency of process innovation in Chapter 6 and the theory underpinning the ordered logit model is discussed in detail in section 6.4.

A vector of variables representing the characteristics of business I, referred to as Z_i in equation 7.1, are included in the estimations that follow. These variables include the age of the business, the size of the business, as measured by the number of employees, whether the business is indigenous or foreign-owned and the rate of growth in turnover over the three-year reference period between 2001 and 2003. These variables and how they are measured are set out in Table 6.4 in the previous Chapter.

Research and development activity in business I, referred to as R_i in equation 7.1, is measured using a binary variable taking a value of 1 if the business performed R&D in the three-year period between 2001 and 2003. Also, a binary variable is included taking a value of 1 if business i had a dedicated R&D department during the same three-year period.

Proximity between business i and the relevant interaction agent, j, referred to as P_{ij} in equation 7.1, is measured using a five point interval measure of the average one-way driving time. These intervals range from less than half and hour, half to one hour, one to two hours, two to four hours and greater than four hours. The latter interval includes interaction agents that are located outside of Ireland.

Separate estimations are conducted for interaction for product innovation and process innovation. The results of these estimations are reported in Table 7.4 and 7.5 respectively.

7.2.1 Proximity and the Frequency of Interaction for Product Innovation

Table 7.4 presents the results of an ordered probit estimation of the frequency of interaction for product innovation by interaction agent. It presents estimated coefficients, standard errors of those estimates and marginal effects for each variable. The analysis of the determinants of the frequency of interaction with each agent is presented in the order in which they are reported in Table 7.4 but there are summary

Table 7.4 provides no evidence that geographic proximity increases the frequency of interaction for product innovation with any of the interaction agents. The only significant effect is found for innovation supporting agencies, which actually shows a negative association between proximity and interaction frequency.

Also, it is notable in Table 7.4 that there is a lack of consistency in statistically significant explanatory variables across each interaction agent. There are no variables that are significantly associated with the frequency of interaction with all agents. This indicates that there are different factors explaining the frequency of interaction for product innovation with each agent. In each estimation interaction with at least one other interaction agent has a significant positive estimated coefficient. It is striking that the incidence of R&D has a significant association only with the frequency of interaction with customers, and is insignificant for all other interaction agents.

Table 7.4 – Ordered Probit Model of the Frequency of Interaction for Product Innovation by Interaction Agent										
	Customer		**Supplier**		**Competitor**		**Academic**		**Agency**	
	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal
Business Characteristics										
Age	-0.007	-0.003	-0.001	0.000	0.015 ***	0.001	0.005	0.000	-0.008	0.000
	(-1.15)		*(-0.12)*		*(1.61)*		*(0.84)*		*(-1.27)*	
Size	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(-1.17)		*(-0.03)*		*(-0.55)*		*(-0.30)*		*(-0.05)*	
Foreign Ownership	0.050	0.020	0.342	0.112	0.063	0.004	0.099	0.005	-0.523 ***	-0.029
	(0.22)		*(1.50)*		*(0.22)*		*(0.31)*		*(-1.85)*	
Turnover Growth	0.020	0.008	-0.023	-0.007	0.082 **	0.006	0.066 **	0.003	0.027	0.002
	(0.64)		*(-0.72)*		*(2.40)*		*(1.88)*		*(0.81)*	
Sector										
ICT	0.363	0.144	-0.256	-0.080	0.374	0.029	-0.239	-0.011	0.027	0.002
	(1.50)		*(-1.07)*		*(1.19)*		*(-0.79)*		*(0.09)*	
Chem/Pharm	-0.153	-0.061	0.126	0.041	-0.436	-0.025	0.046	0.002	0.238	0.016
	(-0.62)		*(0.51)*		*(-1.41)*		*(0.16)*		*(0.84)*	
Research and Development										
Perform RD	0.468 ***	0.181	0.005	0.002	-0.169	-0.013	0.435	0.018	-0.085	-0.005
	(1.66)		*(0.02)*		*(-0.45)*		*(1.15)*		*(-0.24)*	
R&D Dept	0.199	0.079	0.036	0.012	-0.086	-0.006	-0.177	-0.009	0.730 *	0.044
	(0.76)		*(0.14)*		*(-0.27)*		*(-0.55)*		*(2.55)*	
Frequency of Interaction										
Customer			0.421 *	0.136	0.114	0.008	-0.120	-0.006	-0.061	-0.004
			(3.75)		*(0.86)*		*(-0.86)*		*(-0.47)*	
Supplier	0.387 *	0.154			0.097	0.007	0.333 *	0.017	-0.116	-0.007
	(4.23)				*(0.85)*		*(2.79)*		*(-1.03)*	

Table 7.4 continued - Ordered Probit Model of the Frequency of Interaction for Product Innovation by Interaction Agent										
	Customer		**Supplier**		**Competitor**		**Academic**		**Agency**	
	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal
Frequency of Interaction										
Competitor	0.103	0.041	0.072	0.023			0.044	0.002	0.257 **	0.015
	(1.08)		*(0.73)*				*(0.37)*		*(2.39)*	
Academic	0.074	0.029	0.135	0.044	0.149	0.010			0.394 *	0.023
	(0.69)		*(1.27)*		*(1.12)*				*(3.54)*	
Agency	0.063	0.025	0.009	0.003	0.453 *	0.032	0.500 *	0.026		
	(0.59)		*(0.08)*		*(3.18)*		*(3.47)*			
Proximity to Interaction Agent	0.115	0.046	0.001	0.000	0.151	0.010	-0.025	-0.001	-0.179 ***	-0.011
	(1.29)		*(0.02)*		*(1.45)*		*(-0.29)*		*(-1.69)*	
N	146		131		87		87		96	
Log-likelihood	-144.86		-154.88		-114.66		-108.02		-116.33	
LR $chi^2(13)$	44.79		25.33		30.92		35.20		43.70	
Prob > chi^2	0.0000		0.0209		0.0035		0.0008		0.0000	
Pseudo R^2	0.1339		0.0756		0.1188		0.1401		0.1581	

Source: Author's survey

Notes:

1. *** Significant at 1% level
   ** Significant at 5% level
   * Significant at 10% level
2. Z-statistics are reported in parentheses.
3. There are five outcomes in each ordered probit estimation. These are no interaction, rare, regular, frequent and continuous interaction. Marginal effects are computed for each outcome. In every case above the marginal effect reported relates to the fifth outcome, continuous interaction. Marginal effects are computed at variable means.

Interaction with Customers for Product Innovation

Considering the frequency of interaction with customers first, whether a business performs R&D has a significant association with the frequency of interaction with customers. This means that businesses that perform R&D are more likely to interact more frequently with customers for innovation. This may be required to ensure R&D effort is focused on the needs of customers. The development element of R&D is typically associated with improving features and functionality of existing products and may need considerable contact with potential users of these products.

Interaction with suppliers is positively associated with the frequency of interaction with customers (marginal effect is 0.154). It should be noted here that interaction with customers is positively associated with the frequency of interaction with suppliers (marginal effect is 0.136). Businesses that are interacting more frequently with customers interact more frequently with suppliers and *vice versa*. This indicates that businesses may be characterised as being more or less open to interaction for innovation and successful interaction with one of these interaction agents may encourage businesses to interact for innovation with other agents. It is not necessarily the case that interaction with customers and suppliers for product innovation are discrete or independent activities. It is possible to envisage situations where new product development in response to customer demand requires support from suppliers of equipment, materials and/or services to be realised.

None of the business characteristic variables are statistically significant predictors of the frequency of interaction with customers. This means that business age, size, whether it is foreign or indigenous, rate of turnover growth and sector do not significantly affect the frequency with which Irish high-technology businesses interact with customers for innovation. It is notable that the size of the business does not emerge as a significant effect on the frequency of interaction with customers (or indeed with any of the other interaction agents). There are a priori reasons for expecting that size would have a negative association with the frequency of interaction for innovation. Smaller businesses have access to fewer resources, including resources for R&D, and may be expected to rely to a greater extent on external sources of knowledge for innovation. This is not however supported by the results presented here for interaction for product innovation.

As expected, based on the discriminant analysis presented in Section 7.1.1, geographic proximity is not found to be a significant predictor of the frequency of interaction with customers. This finding and similar findings for each of the other interaction agents is discussed in Section 7.2.3 when conclusions and policy implications are considered.

Interaction with Suppliers for Product Innovation

The only variable that emerges as a significant predictor of the frequency of interaction with suppliers is interaction with customers. As already noted, this may indicate that businesses, to meet customer needs for new and improved products, may require greater support from suppliers. As was seen in relation to customer interaction, none of the business characteristic variables are significant predictors of the frequency of interaction with suppliers. Geographic proximity also does not significantly affect the frequency of interaction with suppliers.

Interaction with Competitors for Product Innovation

The age of the business is a significant predictor of the frequency of interaction with competitors, though the marginal effect (0.001) is small relative to the other significant variables affecting the frequency of interaction with competitors. The positive coefficient is consistent with descriptions of the emergent Silicon Valley which Saxenian describes as an American variant of the industrial districts of Europe (1990). She states that what emerges are “networks of specialist producers that both compete and cooperate in response to fast-changing global markets” (1990:91). Saxenian stresses the importance of networks of individuals as conduits for knowledge spillovers for innovation, and while there is no evidence in this thesis that the Irish high-technology businesses are operating as if in a cluster such as Silicon Valley, longer established businesses may have developed stronger networks among other businesses in their industry, even competitors. Saxenian contends that “professional respect, loyalties and friendships” or informal networks (1990:97) are important sources of knowledge spillovers. The significant positive effect of the age of the business on the frequency of interaction with competitors may reflect the fact that older businesses may have developed networks within their industry and may also have built sufficient trust to facilitate knowledge sharing among competing businesses.

A significantly positive association is found between the rate of growth in turnover and the frequency of interaction for product innovation with competitors. This means that businesses with higher levels of growth in turnover are likely to interaction more frequently with competitors. This may indicate that as businesses grow market share and become more firmly established in a market they may be less reluctant to share knowledge with competitors. Alternatively, businesses with growing market shares may be more concerned with the activities of competitors and may have a greater incentive to stay aware of competitors' activities.

The frequency of interaction for product innovation with competitors is also significantly positively associated with the frequency of interaction with innovation-supporting agencies. This is the only interaction variable that has a significant association with interaction with competitors. This finding may also reflect the role of innovation-supporting agencies in supporting linkages and networks within sectors. Until recently Irish innovation-supporting agencies have been organised on a sectoral basis. While businesses in the same sector do not necessarily compete, especially on the Irish market, the innovation-supporting agencies may work with businesses in the same markets and potentially competing with each other on international markets. Through initiatives such as mentoring programmes and trade exhibitions, innovation-supporting agencies act to bring together businesses that operate in similar markets, which may result in the spillover of knowledge for innovation. Innovation-supporting agencies also work with industry associations and lobby groups which may act as a conduit for knowledge-sharing between potentially competing businesses.

Once again, in relation to interaction with competitors, proximity is not a significant predictor of the frequency of interaction. This does not mean that businesses may be able to learn more about competitors located closer to them, though for the businesses in this study this is not done through business-to-business interaction.

Interaction with Academic-Based Researchers for Product Innovation

In relation to academic-based researchers the most notable finding is that the incidence of R&D does not significantly affect the frequency of interaction. *A priori* it is expected that businesses engaged in R&D have stronger links with academic-based researchers. This is not supported by the evidence of this study.

The frequency of interaction with innovation-supporting agencies is a significant factor explaining the frequency of interaction with academic-based researchers. A key role of innovation-supporting agencies is encouraging research collaboration between businesses and third-level institutions. This is a strong feature of the government's Strategy for Science, Technology and Innovation (Department of Enterprise Trade and Employment, 2006). One of the key elements of this new strategy is increasing collaboration between industry and third-level institutes (2006:9). The result here suggests that innovation-supporting agencies are successful in increasing the frequency of interaction between businesses and third-level institutions. However, whether such interaction is beneficial for innovation at the business-level is questionable according to the negative association between the probability of innovation in a business and the frequency of interaction with academic-based researchers reported in section 6.4.

The frequency of interaction with suppliers is also a significant positive predictor of the frequency of interaction with academic-based researchers. There is no clear reason to explain why greater levels of interaction with suppliers, as opposed to, say, interaction with customers, should be associated with more interaction with academic-based researchers. Businesses with higher levels of growth in turnover are also significantly more likely to interact more frequently with academic-based researchers.

None of the other business characteristics variables are significant predictors of the frequency of interaction for product innovation with academic-based researchers, and just as with the other interaction agents considered so far geographic proximity is not associated with more frequent interaction.

Interaction with Innovation-Supporting Agencies for Product Innovation

Foreign businesses have a lower frequency of interaction for product innovation with innovation-supporting agencies than indigenous businesses. Ownership is measured using a binary variable taking a value of 1 if the business is foreign-owned. The marginal effect (-0.029) is large relative the marginal effects of other significant variables. This indicates that indigenous businesses in the high-technology sectors may perceive a benefit for innovative activity of interaction with innovation-supporting agencies. There is likely to be a difference in the nature of the interaction with innovation-supporting agencies between indigenous and foreign-owned businesses, which are serviced by Enterprise Ireland and IDA Ireland respectively. While both indigenous and foreign-owned businesses benefit from financial grant assistance from innovation-supporting agencies, indigenous businesses may also benefit from Enterprise Ireland initiatives such as mentoring programmes, assistance in export markets and the use of lower-cost office facilities. These may be provided in a way that facilitates the sharing of knowledge for product innovation. Foreign ownership is the only business characteristic variable that is significantly associated with the frequency of interaction with innovation-supporting agencies.

Whether a business has a dedicated R&D department is positively associated with the frequency of interaction with innovation-supporting agencies. The marginal effect is relatively strong (0.044). This may be driven by the need for businesses to show that they are actively engaged in R&D in order to get R&D funding from innovation-supporting agencies, which is a key element of interaction with innovation-supporting agencies for innovation. This may be more easily achieved where there is a dedicated R&D function in the business.

The frequency of interaction with both competitors and academic-based researchers is found to be significant indicator of interaction with innovation-supporting agencies. This may reflect the business and university networking initiative of Irish enterprise development agencies. These agencies are engaged in technology transfer initiatives and funding for research in third-level so these agencies may encourage businesses that interaction with them for innovation to co-operate with or seek assistance from academic-based researchers. Also, since innovation–supporting agencies tend to be operate on a sectoral basis and organise sectoral conferences, networks and trade missions businesses may be more likely to encounter and interact with competitors when interacting with innovation-supporting agencies.

There is a negative relationship between geographic proximity and the frequency of interaction with innovation-supporting agencies. This means that the greater the distance to innovation-supporting agencies the more frequently high-technology businesses will interact with them for innovation. Since innovation-supporting agencies comprise both regional organisations, such as County Enterprise Boards, and support agencies, such as Enterprise Ireland, which have offices throughout the country, this result suggests that high-technology businesses are by-passing local offices of national agencies and local support agencies in relation to innovation. Given the importance of international markets to businesses in the high-technology sectors, this result may be explained by more frequent interaction among high-technology businesses with international offices of the national support agencies.

Overall, each model reported in Table 7.4 is significant. The likelihood ratio (LR) X^2 tests the hypothesis that there is no difference between the estimated model and the constant only model (i.e. that each coefficient is zero). The p-value (0.0000) is less than 0.05 in each case, which indicates that this hypothesis can be rejected and the estimated models are significant indicators of the probability of the frequency of interaction for product innovation with each interaction agent.

Before considering the important policy implications of the results presented in Table 7.4, the next section considers the drivers of the frequency of interaction for process innovation in Irish high-technology businesses.

7.2.2 Proximity and the Frequency of Interaction for Process Innovation

Modelling interaction for process innovation in the same way as product innovation, Table 7.5 presents the results of an ordered probit estimation of the frequency of interaction for process innovation by interaction agent.

From Table 7.5 it can be seen that proximity to interaction agents does not significantly affect the frequency of interaction with those agents. In addition to the results reported and discussed in Section 7.2.1 relating to interaction for product innovation, it is clear that interaction for both product and process innovation for Irish high-technology businesses is independent of the proximity between those businesses and interaction agents. This appears to be consistent across all interaction agents.

In general in Table 7.5, just as with interaction for product innovation it is notable that no single variable has a significant effect on the frequency of interaction for process innovation. While no significant sectoral effects are seen in relation to interaction for product innovation with any interaction agent, businesses in the *ICT* sector interact with customers for process innovation more frequently and with suppliers less frequently than businesses in the reference sector, *Electronic Devices and Engineering*. The factors driving interaction with each agent are discussed in the same order they are reported in Table 7.5.

Table 7.5 – Ordered Probit Model of the Frequency of Interaction for Process Innovation by Interaction Agent										
	Customer		**Supplier**		**Competitor**		**Academic**		**Agency**	
	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal
Business Characteristics										
Age	-0.003	-0.001	0.013 **	0.001	0.013	0.000	-0.002	0.000	-0.003	0.000
	(-0.51)		(2.17)		(1.21)		(-0.20)		(-0.27)	
Size	0.000	0.000	-0.001	0.000	0.001	0.000	0.000	0.000	0.001	0.000
	(0.34)		(-1.42)		(0.87)		(0.10)		(1.48)	
Foreign Ownership	-0.168	-0.049	0.507 **	0.050	-0.741 **	-0.020	0.130	0.001	-0.113	-0.001
	(-0.68)		(2.08)		(-2.22)		(0.38)		(-0.36)	
Sales Growth	0.016	0.005	0.030	0.003	0.104 *	0.003	0.034	0.000	0.019	0.000
	(0.49)		(0.93)		(2.79)		(0.88)		(0.51)	
Sector										
ICT	0.735 *	0.231	-0.747 *	-0.114	0.312	0.010	0.298	0.004	0.046	0.001
	(2.82)		(-2.95)		(0.87)		(0.82)		(0.14)	
Chem/Pharm	-0.207	-0.058	0.200	0.018	0.184	0.006	-0.018	0.000	0.122	0.002
	(-0.79)		(0.79)		(0.53)		(-0.06)		(0.40)	
Research and Development										
Perform RD	0.235	0.066	0.012	0.001	-0.044	-0.001	0.936 **	0.006	0.168	0.002
	(0.79)		(0.04)		(-0.10)		(2.23)		(0.44)	
R&D Dept	0.010	0.003	0.209	0.021	0.192	0.006	-0.601 ***	-0.006	0.177	0.002
	(0.04)		(0.84)		(0.62)		(-1.78)		(0.59)	
Frequency of Interaction										
Customer			0.314 *	0.034	0.204	0.006	-0.015	0.000	-0.124	-0.002
			(3.83)		(1.58)		(-0.12)		(-1.07)	

Table 7.5 continued– Ordered Probit Model of the Frequency of Interaction for Process Innovation by Interaction Agent

	Customer		**Supplier**		**Competitor**		**Academic**		**Agency**	
	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal	Coefficient	Marginal
Supplier	0.320 *	0.094			0.030	0.001	0.216 ***	0.002	-0.046	-0.001
	(3.45)				(0.20)		(1.70)		(-0.36)	
Competitor	0.328 *	0.096	-0.017	-0.002			0.091	0.001	-0.032	0.000
	(2.73)		(-0.14)				(0.62)		(-0.24)	
Academic	0.127	0.037	0.344 *	0.037	0.171	0.005			0.511 *	0.007
	(0.91)		(2.63)		(1.04)				(3.83)	
Agency	-0.124	-0.036	-0.073	-0.008	0.095	0.003	0.821 *	0.008		
	(-1.02)		(-0.64)		(0.58)		(5.07)			
Proximity to Interaction Agent	0.034	0.010	0.106	0.011	0.052	0.002	0.021	0.000	0.002	0.000
	(0.40)		(1.37)		(0.44)		(0.22)		(0.02)	
N	119		124		72		76		81	
Log-likelihood	-148.70		-154.99		-87.25		-79.29		-96.99	
LR $chi^2(13)$	36.34		42.79		29.88		45.17		25.20	
Prob > chi^2	0.001		0.000		0.005		0.000		0.022	
Pseudo R^2	0.109		0.121		0.146		0.222		0.115	

Source: Author's survey

Notes:
1. *** Significant at 1% level
   ** Significant at 5% level
   * Significant at 10% level
2. Z-statistics are reported in parentheses.
3. There are five outcomes in each ordered probit estimation. These are no interaction, rare, regular, frequent and continuous interaction. Marginal effects are computed for each outcome. In every case above the marginal effect reported relates to the fifth outcome, continuous interaction. Marginal effects are computed at variable means.

Interaction with Customers for Process Innovation

The frequency of interaction with customers for process innovation is significantly positively associated with the frequency of interaction with suppliers and competitors. The former finding is similar to that seen in relation to interaction with customers for product innovation and again suggests backward and forward linkages are complementary for innovation. These are the only two interaction variables that are significant predictors of the frequency of interaction with customers.

It is noteworthy that the incidence of R&D is not significantly associated with the frequency of interaction with customers for process innovation, as it was in relation to product innovation. This may suggest that R&D in these businesses is more focused on product innovation, which, as reported in Table 7.4, would be more likely to induce businesses to interact more frequently with customers.

None of the business characteristics variables have a significant effect on the frequency of interaction with customers, though businesses in the *ICT* sector are significantly more likely to interact with customers for process innovation than businesses in the reference sector, *Electronic Devices and Engineering*.

Just as it was in relation to product innovation, geographic proximity does not significantly affect the frequency of interaction with customers for process innovation.

Interaction with Suppliers for Process Innovation

Business age is a significant predictor of the frequency of interaction with suppliers for process innovation, though the marginal effect is relatively small (0.001). The positive coefficient indicates that older businesses tend to interact with suppliers more frequently than younger ones. Foreign ownership has a significant, positive estimated coefficient which indicates that there is a greater probability that foreign-owned businesses interact more frequently with suppliers than indigenous businesses. While *ICT* businesses are more likely to interact with customers, they are less likely than *Electronic Devices and Engineering* businesses to interact with suppliers for process innovation.

The close association between interaction with customers and suppliers for process innovation is also evident in the significantly positive coefficient for the frequency of interaction with customers. Businesses that interact more frequently with customers are more likely to interact frequently with suppliers for process innovation. As discussed earlier this reflects an openness in a business to interaction along the supply chain, indicating complementarities between backward and forward linkages. The only other significant interaction variable is in relation to academic-based researchers. Once again, there is no evidence that proximity increases the frequency of interaction.

Interaction with Competitors for Process Innovation

Foreign-owned businesses have less frequent interaction for process innovation with competitors relative to indigenous businesses. The marginal effect again is relatively small (-0.020). It was noted in Chapter 5 that indigenous businesses in the study tend to be smaller than foreign-owned businesses and the finding of greater frequency of interaction with competitors among indigenous businesses is consistent with the type of interaction described by Saxenian (1990) in Silicon Valley and Scott (1988) and Castells and Hall (1994) in Emiglia-Romagna. These studies stress an important role for interaction among small and medium-sized enterprises as a driver of innovation among businesses in a region.

However, it should be noted that proximity to competitors does not have a significant association with the frequency of interaction with them. This suggests that while indigenous businesses may have more frequent interaction for process innovation than foreign-owned businesses, there is no evidence that this interaction is spatially bounded or occurs at a local or regional level. Also, business size is not a significant predictor of the frequency of interaction with competitors, which would also be inconsistent with the Silicon Valley and Emiglia-Romagna cases referred to above.

Interaction with Academic-Based Researchers for Process Innovation

It is notable that whether a business performs R&D only has a significant effect on the frequency of interaction with academic-based researchers, and is insignificant for all other interaction agents. Cohen and Levinthal (1990) argue that businesses may perform R&D not only to generate new innovations directly but also to enhance their absorptive capacity. Absorptive capacity is the ability to identify, evaluate and exploit external knowledge. Academic-based research is an important source of external knowledge. The interaction with academic-based researchers may arise from links between researchers within the business and researchers at third-level institutions.

Researchers within the business may be able to interact more easily with academic-based researchers due to shared experiences in the research process or a shared 'language of research'. It is notable, however, that there is a significant negative relationship between the frequency of interaction with academic-based researchers and whether businesses have a dedicated R&D department. This suggests that businesses with more formalised R&D structures may keep R&D activity in-company compared to businesses that perform R&D on a less formal basis who use academic – based researchers to supplement R&D effort.

The frequency of interaction for process innovation with academic-based researchers is significantly positively associated with the frequency of interaction with suppliers and innovation-supporting agencies. The significant positive relationship between suppliers and academic-based researchers was also found in the estimation of the determinants of the frequency of interaction with suppliers and was discussed above.

Just as with the other interaction agents there is no evidence of an association between geographic proximity and the frequency of interaction.

Interaction with Innovation-Supporting Agencies for Process Innovation

The frequency of interaction for process innovation with innovation-supporting agencies is significantly positively associated with the frequency of interaction with academic-based researchers. This may reflect the involvement of enterprise support agencies in attempts to development linkages between businesses and third-level institutions, through technology transfer initiatives and the funding of research in third-level colleges.

Again, there is no evidence of an association between geographic proximity and the frequency of interaction with innovation-supporting agencies.

7.2.3 Conclusions and Policy Implications

The clear conclusion from the analyses presented in this Chapter is that interaction for product and process innovation in Irish high-technology businesses does not occur on a regional or local basis. Geographic proximity is not found to be a significant predictor of the frequency of interaction with customers, suppliers, competitors or academic-based researchers. That the estimated coefficients are insignificant means that there is no evidence that the businesses in this study are more attracted to closer interaction agents. The specific features of the Irish economy may explain this finding. Ireland has a large number of multinational businesses whose customers, suppliers and competitors are more likely to be other multinational businesses. Ireland is a very open economy with a relatively small domestic market, so a large number of indigenous businesses in the sectors under consideration may be exporting their products. These specific characteristics of the Irish economy may increase the relative importance of international interaction agents and lessen the scope for interaction with local customers, suppliers and competitors.

Geographic proximity is found to have a significant effect only on the frequency of interaction with innovation-supporting agencies, and in this case there is a negative relationship between geographic proximity and interaction frequency. This finding is pertinent to attempts by Irish policy-makers to develop clusters of businesses in high-technology sectors and indeed must call into question the appropriateness of cluster-based approaches to the development of innovative Irish high-technology sectors. This is discussed in more detail in the final section of this Chapter.

The finding that interaction for innovation in these sectors does not occur on a regional or local basis prompts the question of whether there are any elements of the local or regional environment that affects innovation. As discussed in Section 2.5, there is support for a positive association between agglomeration of economic activity and innovation. These agglomeration advantages are categorised as localisation advantages and urbanisation advantages by Parr (2002). The effect of agglomeration on innovation in Irish high-technology businesses is the focus of the next section.

7.3 Agglomeration Effects on Innovation in Irish High-Technology Businesses

As concluded in the last section, there is little evidence in this thesis to indicate that the innovation performance of Irish high-technology businesses benefits from geographic proximity to suppliers, customers and competitors. Interaction with these other businesses for product and process innovation does not occur on a regional or local basis and the frequency of that interaction seems to be independent of the geographical distance between the interaction agents.

Section 2.5 considers how businesses may benefit from their location within an agglomeration of economic activity. Such an agglomeration may be characterised by a concentration of businesses in the same or similar industries, referred to as localisation economies, or by a concentration of businesses in unrelated industries, referred to as urbanisation economies.

Marshallian localisation economies are derived from the availability of shared intermediate inputs at lower cost due to scale economies, access to a thick skilled labour market and knowledge spillovers within a geographically bounded area (Parr, 2002). The benefit of having intermediate inputs locally may comprise both cost and knowledge elements. Businesses may benefit from lower cost inputs as suppliers achieve economies of scale due to the co-location of many potential customers. Businesses may also acquire knowledge from these suppliers through interaction. Similarly in relation to the availability of a local thick skilled labour market, businesses gain through lower search costs for labour, but also through the knowledge that diffuses among businesses through the movement of labour. This means that knowledge spillovers within a specific area may include spillovers from supplier of intermediate inputs and those facilitated by labour movement but are distinct from the cost benefits arising from these sources. Since this study is concerned with innovation the focus in relation to localisation economies is the knowledge spillovers element.

Urbanisation economies are derived from the common location of businesses in different and unrelated sectors. The urban-hierarchy model suggests that a business' location in an urban environment may support innovation by benefiting from what Gordon and McCann call "a rich 'soup' of skills, ideas, technologies, and cultures within which new compounds and forms of life can emerge and/or a permissive environment enabling unconventional initiatives to be brought to the marketplace" (2005:528).

The focus of this section is the extent to which innovation in Irish high-technology businesses is influenced by the presence of localisation and/or urbanisation economies. While the survey data provides evidence of local or regional knowledge spillovers through interaction with suppliers, customers, competitors, academic-based researchers and innovation-supporting agencies, secondary data is required in relation to other elements of localisation economies and urbanisation economies. Indicators based on secondary data are presented in the next section.

7.3.1 Indicators of Localisation and Urbanisation Advantage

Secondary data is required to formulate indicators of agglomeration economies. First, in relation to the source of localisation advantage not already explored in the section 7.2., data on the concentration of labour within a sector in a geographical location is required. Parr identifies "access to a pool of labour with specific occupational skills and the accompanying avoidance of labour shortages or bottlenecks" (2002:158) as a source of localisation advantage.

Labour Market Share

Where a region has a greater share of labour with occupational skills relevant to a specific sector, businesses in that region and sector may be considered more likely to be able to benefit from accessing the knowledge in that labour market. This means that data on the regional concentration of sector-specific skills is required. The Census of Industrial Production (CSO, 2002) reports numbers employed by NACE code by county. Table 7.6 presents a geographical spread of total persons engaged in relevant NACE codes, as well as each regional category's percentage of the total persons engaged in each sector. This table is based on a request by the author to the Central Statistics Office. Confidentiality issues limit the extent to which the CSO can report total persons engaged by NACE code and by area. The NACE codes corresponding to each of the three sectors in this study are set out in Table 4.6 to 4.8, where survey coverage and representativeness are reported. To achieve an appropriate sectoral classification, three regional categories were derived from the eight NUTS 3 regions. The categorisation is based on existing NUTS 3 regions, the geographical spread of the businesses in the survey data and, as far as possible, aggregation between contiguous regions where there is a large amount of commuting. The three regional categories are *Border*, *Midlands* and *West* (BMW), *Dublin* and *Mid-East* and *Mid-West*, *South-East* and *South-West*.

Table 7.6 – Total Persons Engaged by Selected NACE 2 Digit Codes by Aggregated NUTS 2 Region in 2002

	Regions						
	Border, Midland and Western		Dublin and Mid-East[1]		Mid-West, South-East and South-West		Total
NACE Codes	Total Engaged	Percent in Region[2]	Total Engaged	Percent in Region	Total Engaged	Percent in Region	
22, 30	4,100	12.4%	19,338	58.3%	9,726	29.3%	33,164
24	4,497	17.7%	8,591	33.8%	12,348	48.5%	25,436
29, 31 -35	20,663	32.0%	18,401	28.5%	25,448	39.4%	64,512
Total	29,260		46,330		47,522		123,112

Source: Census of Industrial Production, 2002 (CSO, 2002) based on a special request by the author.

Notes: 1. Includes non-attributable records to protect confidentiality
2. The persons engaged in selected NACE codes in the region as a percentage of total persons engaged in those NACE codes.

The percentage of total persons employed in a business' sector in their region is used as a proxy to measure the extent to which that business has access to a localised thick skilled labour market. This, in addition to the survey data on interaction with suppliers, customers and competitors, is used to measure localisation advantages for innovation. The unavailability of more detailed regional data on numbers employed limits the extent to which the presence of localised skilled labour markets can be identified. Despite this limitation, it is important to include an indicator of this important element of localisation economies, which is a conduit for the flow of knowledge.

In relation to urbanisation advantages, several indicators are used, all of which are derived from secondary sources. Urbanisation advantages are derived from the common location of businesses in different industries and are most commonly associated with urban locations. Parr states that urbanisation economies are based on "the availability of a range of municipal services, public utilities, transportation and communication facilities, the existence of a wide variety of business and commercial services and complementarity in labour supply" (2002:159). Some of these advantages may be more relevant to innovation than others. For example, complementarity of labour supply may stimulate new knowledge creation as a function of the diversity within cities suggested by Jacobs (1969) and Glaeser et al (2000). Transportation and communication facilities may also support the transmission of knowledge by facilitating more frequent interaction between businesses. The indicators used to measure urbanisation advantages are based on these sources. These are the population density, the percentage employed in technical occupations and the percentage of third-level graduates from scientific disciplines within the area in which the business is located, the driving time to the nearest major airport and the business' location within a gateway or hub as identified in the National Spatial Strategy (Department of Environment and Local Government, 2002). These measures are described in detail in the subsequent sections and summarised in Table 7.8.

Population Density

The extent to which a business' location can be characterised as an urban area is indicated by the population density of the geographical area. The geographical area is the electoral division or the city borough in which the business is located. Population density is measured as the population divided by the area of each electoral division. An adjustment is made for electoral divisions within city boroughs. For city boroughs the mean population density of all electoral districts in which there are businesses within the survey is used. This adjustment is made because, for the purpose of this study, differences in population densities between urban areas and rural areas is more relevant than differences between administrative districts within urban areas. Volume 1 Table 6 of the 2002 Census (CSO, 2002) publishes the population and area in hectares of each electoral division. The businesses in the survey sample provide addresses and so their geographical areas can be identified. The mean population density in the sample is 22.67 persons per hectare and the standard deviation is 16.94 persons per hectare. The population density ranged from a low of 0.18 persons per hectare to a high of 61.9 persons per hectare.

Percentage Employed in Technical Occupations

Two indicators are used in relation to the complementarity of labour supply. The first is the percentage of employment in technical occupations in the business' county. The second is the percentage of third-level graduates with science-based degrees in the business' county. These are similar measures to those used by Roper (2001) to classify counties into urban categories. The percentage of persons employed in technical and professional occupations in each county and city borough is contained in Volume 6 Table 2 of the Census of Industrial Production (CSO, 2002) which reports the persons aged 15 or over in the labour force in each county classified by broad occupational group. The number of *Technical and Professional* is one of the occupational classifications. For each county the number employed in this category is divided by the total persons in all occupations. The percentage of persons employed in technical occupations for each county is presented in Table 7.7.

Percentage of Third-Level Graduates from Scientific Disciplines

Roper (2001) makes a distinction between urban, urban-periphery, rural and second-centre locations in Ireland. Second-centre locations are those with a major university campus. The estimation in Table 7.10 includes a variable for the frequency of interaction for innovation with academic-based researchers. Apart from this benefit, businesses gain from the presence of a university campus in their region to the extent that this creates a source of skilled labour in that region. The presence of a university campus may not result in higher levels of skilled labour where graduates leave the region where the campus is located. Also, the concentration on universities omits the institutes of technologies which are more widely dispersed around the country.

The population of each county with a third level qualification attained after two or more years of study classified by main subject area is contained in Volume 7 Table 23 of Census 2002 (CSO, 2002). The subjects considered relevant for high-technology businesses are *Life Sciences and Medical Laboratory Science*, *Physical Sciences and Chemistry*, *Mathematics and Statistics*, *Computing and Information Technology*, *Engineering and Architecture* and *Medical and Related Qualifications*. The qualification classifications excluded are *Education*, *Art*, *Humanities, Social Sciences, Business and Law*, *Agriculture, Forestry, Fishery and Veterinary*, *Tourism and other*, *Other third level qualifications* and those that did not state the qualification classification. The total number of persons with a third level qualification in the county is divided by the total number of persons with any third level qualification in the county. The percentage of third-level graduates from scientific disciplines for each county is presented in Table 7.7.

Table 7.7 - Percentage Employed in Technical Occupations and Percentage of Third-Level Graduates from Scientific Disciplines by City and County, 2002 (percentage of total employed and total third-level graduates)

	Percentage Employed in Technical Occupations	*Percentage of Third-Level Graduates from Scientific Disciplines*
Carlow	14%	36%
Dublin City and County	19%	32%
Dublin City	18%	31%
Dún Laoghaire-Rathdown	24%	31%
Fingal	17%	34%
South Dublin	15%	34%
Kildare	16%	35%
Kilkenny	15%	35%
Laoighis	14%	35%
Longford	13%	33%
Louth	15%	37%

Table 7.7 continued - Percentage Employed in Technical Occupations and Percentage of Third-Level Graduates from Scientific Disciplines by City and County, 2002 (percentage of total employed and total third-level graduates)

	Percentage Employed in Technical Occupations	*Percentage of Third-Level Graduates from Scientific Disciplines*
Meath	15%	35%
Offaly	12%	34%
Westmeath	16%	37%
Wexford	13%	34%
Wicklow	16%	31%
Leinster	*17%*	*33%*
Clare	16%	36%
Cork City and County	18%	36%
Cork City	18%	36%
Cork County	17%	37%
Kerry	14%	35%
Limerick City and County	17%	39%
Limerick City	15%	35%
Limerick County	18%	40%
Tipperary North	14%	35%
Tipperary South	14%	35%
Waterford City and County	15%	38%
Waterford City	15%	41%
Waterford County	15%	37%
Munster	*16%*	*37%*
Galway City and County	19%	36%
Galway City	23%	36%
Galway County	16%	35%
Leitrim	14%	36%
Mayo	15%	36%
Roscommon	15%	38%
Sligo	18%	40%
Connacht	*17%*	*37%*
Cavan	12%	37%
Donegal	14%	36%
Monaghan	13%	35%
Ulster (part of)	*13%*	*36%*
State	*17%*	*34%*

Source: Volume 6 Table 2 and Volume 7 Table 23 of Census 2002 (CSO, 2002)

It is notable in Table 7.7 that there is little variation between counties in the percentage employed in technical occupations and the percentage of third-level graduates from scientific disciplines. The former rages from a low of 12% in Offaly to 23% in Galway City and 24% in Dun Laoghaire-Rathdown. The two higher values are unusual, as they are the only observations above 20% and most are clustered between 14% and 17%.

The percentage of third-level graduates from scientific disciplines ranges from a low of 31% in Dublin City, Dun Laoghaire-Rathdown and Wicklow to a high of 41% in Waterford City. The observations tend to be clustered in a range between 34% and 37%.

Driving Time to Nearest Major Airport

Parr (2002:159) identifies the availability of a range of municipal services and transportation facilities as key sources of urbanisation economies. The availability of a major international airport is an important aspect of a city’s transportation infrastructure. The finding that interaction for innovation with customers and suppliers occurs over greater distances and probably internationally would suggest that transport infrastructure is crucially important for Irish high-technology businesses, with an airport an essential part of that infrastructure. There are 10 international airports on the island of Ireland. These are listed in Table 7.8. This study focuses on the major airports, as the greater the range of flights from an airport the greater the accessibility to businesses in the region and for businesses in the region to easily visit interaction agents abroad.

From Table 7.8 it can be seen that Dublin, Belfast, Shannon and Cork airports have significantly greater passenger numbers, more scheduled routes and more airlines operating than the other airports. The distance from the businesses in the survey to the nearest major airport will therefore focus only on these four airports.

Table 7.8 – Passengers, Number of Scheduled Routes and Number of Airlines using each Irish Airport

Airport	Number of Passengers 2005	Number of Scheduled Routes	Number of Airlines
Dublin	18.40	150	88
Belfast International *	4.50	13	5
Shannon	3.30	37	9
Cork	2.70	34	15
Knock	0.53	7	4
Galway *	0.23	6	1
Derry	0.21	5	2
Waterford	0.07	3	1
Kerry	n/a	6	2
Sligo	n/a	1	1

Source: www.dublinairport.com; www.belfastairport.com; www.shannonairport.com; www.corkairport.com; www.knockairport.com; www.galwayairport.com; www.cityofderryairport.com; www.flywaterford.com; www.kerryairport.ie; www.sligoairport.com [All accessed June 14, 2006]

Notes: * The passenger numbers refer to 2004

The distance from the nearest major international airport is expressed as the number of minutes driving time. The airports considered are Dublin, Belfast, Shannon and Cork. The one-way driving time from each of the 183 business to the nearest major airport was estimated using the AA Ireland route planner available on www.aaroadwatch.ie/routes. The mean driving time is 41.7 minutes and the standard deviation is 35.4 minutes. The estimated driving distances range from a low of 7 minutes to a high of 209 minutes.

National Spatial Strategy Gateways and Hubs

Ireland's regional structure is dominated by the Greater Dublin Area. For example, Leinster accounts for 54% of Ireland's total population and 28% of people in Ireland live in County Dublin (CSO, 2006). This regional imbalance was the focus of the *National Spatial Strategy* (Department of Environment and Local Government, 2003) which identified regional gateways and hubs as the conduits of regional development. The National Spatial Strategy identifies nine gateways, Dublin, Cork, Limerick/Shannon, Galway, Waterford, Dundalk, Sligo, Letterkenny and Athlone/Mullingar/Tullamore (Department of Environment and Local Government, 2002:58). These gateways are areas with a large urban population (greater than 100,000) characterized by wide ranges of secondary and third-level educational facilities and large clusters of national/international scale enterprises. They are also focal points in transportation and communications terms and have "city-scale" utilities and amenities (Department of Environment and Local Government, 2002:40).

The Greater Dublin Area stands apart from the other gateways in terms of its size and Businesses are classified based on their location within the Greater Dublin Area, in another gateway (other than Dublin) or in neither. A series of binary variables are identified where the reference group is businesses not located in a gateway.

Table 7.9 summarises the agglomeration indicators described above.

Table 7.9 – Agglomeration Indicators		
Indicator	**Description**	**Source**
Localisation Indicators		
Labour Share	The percentage of total persons engaged in the business' sector located in the relevant region in 2002 (based on consolidated NUTS 2 regions).	Census of Industrial Production, 2002 (CSO, 2002)
Urbanisation Indicators		
Population Density	Population per hectare in the relevant electoral division.	Census 2002, Volume 1 Table 6
Distance to Airport	The estimated one-way driving time from the business to the nearest major airport, expressed in minutes.	www.aaroadwatch.ie/routes
Technical Employment	The percentage of persons in all occupations in the business' county employed in technical and professional occupations in 2002. and Percentage of Third-Level Graduates from Scientific Disciplines by City and County, 2002.	Census 2002, Volume 6 Table 2
Science Education	The percentage of total third-level graduates in the business' county in 2002 that have graduated from a scientific discipline.	Census 2002, Volume 7 Table 23
Hub/Gateway	A dummy variable taking a value of 1 if the business is located in a hub or gateway, other than Dublin, identified in the National Spatial Strategy.	Department of Environment and Local Government, 2002:58
Greater Dublin Area	A dummy variable taking a value of 1 if the business is located in the Greater Dublin Area identified in the National Spatial Strategy.	Department of Environment and Local Government, 2002:58

7.3.2 The Effect of Localisation and Urbanisation Advantages on Innovation

Table 7.10 reports a logit estimation of the probability of introducing new products and new processes on at least a regular basis. These estimations are similar to those reported in Tables 6.4 and 6.7, except the model estimated below also includes variables relating to localisation and urbanisation advantages.

Table 7.10 – Logit estimation of the probability of introducing new products and new processes on at least a regular basis.

	Product Innovation			Process Innovation		
	Co-efficients[1]	Z-stat[2]	Weighted Elasticity	Co-efficients[1]	Z-stat[2]	Weighted Elasticity
Business Characteristics						
Age	0.0035 (0.0186)	1.88***	0.015	-0.0352 (0.0138)	-2.55**	0.023
Size	-0.0020 (0.0012)	-1.59	0.001	0.0046 (0.0026)	1.75***	0.021
Foreign Ownership	-2.0249 (1.5125)	-1.34	0.018	0.4511 (0.8525)	0.53	0.003
Sector						
ICT	-0.8122 (0.6566)	-1.24	0.004	-0.3705 (0.5877)	-0.63	0.004
Chemicals and Pharmaceuticals	-1.3153 (0.6568)	-2.00**	-0.004	-0.2992 (0.6010)	-0.50	-0.001
Research and Development						
Perform R&D	0.9022 (0.6698)	1.42	0.031	2.5676 (0.7152)	3.59*	0.137
R&D Department	0.6386 (0.7515)	0.85	0.013	-0.7389 (0.6415)	-1.15	-0.025
Interaction						
Frequency of Interaction						
Supplier	0.3086 (0.2324)	1.64***	0.033	0.7536 (0.2322)	3.25*	0.030
Customer	0.5780 (0.2324)	2.49**	0.090	0.3372 (0.1823)	1.85***	0.023
Competitor	-0.2725 (0.2768)	-0.98	-0.099	-0.1549 (0.3105)	-0.50	0.002
Academic	-0.6582 (0.3240)	-2.03**	-0.165	-0.6003 (0.3219)	-1.86**	-0.021

Table 7.10 continued– Logit estimation of the probability of introducing new products and new processes on at least a regular basis.						
	Product Innovation			Process Innovation		
	Co-efficients[1]	Z-stat[2]	Weighted Elasticity	Co-efficients[1]	Z-stat[2]	Weighted Elasticity
Frequency of Interaction						
Agency	0.7757	2.06**	0.033	-0.3988	1.22	0.025
	(0.3761)			(0.3270)		
Group Member	2.1212	1.39	-0.014	-0.1529	-0.18	-0.002
	(1.5261)			(0.8309)		
Agglomeration						
Labour Market Share	2.4063	1.07	0.014	0.1364	0.07	0.001
	(2.2439)			(1.9490)		
Population Density	0.0385	2.00**	0.033	0.0123	0.67	0.009
	(0.0192)			(0.0184)		
Distance to Airport	0.0110	0.98	0.000	-0.0053	-0.66	0.013
	(0.0111)			(0.0080)		
Technical Employment	-4.8775	-0.38	-0.003	-3.0345	-0.28	0.003
	(12.8029)			(10.9298)		
Science Education	-7.5630	-0.32	-0.008	15.4106	0.67	-0.049
	(23.3728)			(22.9945)		
National Spatial Strategy						
Hub/Gateway	-0.0778	-0.08	-0.000	0.2244	0.27	0.001
	(0.9531)			(0.8114)		
Greater Dublin Area	-0.7173	-0.54	-0.007	1.5408	1.23	-0.031
	(1.3284)			(1.2536)		
Constant	-0.6397	-0.07		-8.0662	-0.92	
	(9.0586)			(8.7575)		
N	180			175		
Log Likelihood	-56.796			-68.583		
Pseudo R^2	0.3595			0.3125		
LR Chi^2	63.75			62.35		
	(0.0000)			(0.0000)		
Percentage Correctly Predicted						
Overall	85.6%			81.1%		
Innovator	87.9%			83.9%		
Non-Innovator	69.6%			68.8%		

Source: Author’s survey; CSO (2002), Department of the Environment and Local Government (2003); www.aaroadwatch.ie/routes

Notes:
1. Standard errors are reported in parentheses.
2. * Significant at 1% level
** Significant at 5% level
** Significant at 10% level

Before considering the effect of localisation and urbanisation variables, it can be seen that the probability of being a product innovator is significantly positively associated with the age of the business, the frequency of interaction for product innovation with suppliers, customers and innovation-supporting. These results are consistent with the logit estimation of the probability of introducing new products in Table 6.4, with the notable exception that whether a business performs R&D is no longer a significant predictor of the probability of product innovation.

With regard to the agglomeration variables, population density is the only indicator significantly positively associated with the probability of product innovation. This indicates that high-technology businesses located in urban areas are more likely to be product innovators than businesses in less densely populated or rural areas. The weighted elasticity of the population density variable suggests that its effect on the probability of product interaction is relatively large compared to the other significant variables. The weighted elasticity is 0.033, which indicates that a 1% increase in the population density in the geographical area increases the probability of product innovation by 3.3%. While the weighted elasticity associated with the frequency of interaction with customers suggests that it has the largest single effect (a one unit increase in the frequency of interaction increases the probability by 9%), the weighted elasticity of the population density variable is a similar magnitude to the other significant positive variables. This supports the view of cities as conducive to innovation. This is not consistent with Roper (2001) which finds no evidence for Ireland that urban location is associated with an increased probability of innovation, though that study was not concerned only with high-technology businesses.

It is notable that the Greater Dublin Area dummy variable is insignificant, which suggests that there is not a ‘Dublin effect’. It is urban location, rather than simply location within the Dublin area, which has a significant positive effect on innovation in Irish high-technology businesses. Complementarity of labour supply does not appear to be a source of urbanisation advantage for innovation, as both technical employment and the number of science graduates do not significantly affect the probability of product innovation. Finally, accessibility to a major airport also does not significantly affect the probability of product innovation.

As it was in the original estimation in Table 6.4, there is a significant negative association between the probability of product innovation and the frequency of interaction for innovation with academic-based researchers. Also, businesses in the *Chemical and Pharmaceutical* sector are less likely to introduce product innovation compared to the reference sector, *Electronic Devices and Engineering*.

With regard to the probability of regular process innovation, the same significant associations are found in this estimation to those presented in Table 6.7. The probability of regular process innovation is positively associated with (in order of relative importance based on weighted elasticities) whether the business performs R&D, the frequency of interaction with suppliers and customers and the size of the business. The probability of regular process innovation is significantly reduced by the age of business and the frequency of interaction with academic-based researchers. It is notable that the agglomeration variables do not have significant effects on the probability of introducing new processes on a regular basis.

Barthelt, Malmberg and Maskell (2004) use a combination of ‘local buzz’ and ‘global pipelines’ to explain why interaction between businesses within a cluster may be limited and the results reported in Table 7.10 provide some support for this framework. Barthelt, Malmberg and Maskell (2004) make a distinction between local learning among agents within an agglomeration of economic activity and knowledge acquired as a result of developing channels of communication with interaction agents located a greater distance away from the business. The former is referred is to as ‘local buzz’ (Storper and Venables, 2002) and the latter is called ‘global pipelines’. Barthelt, Malmberg and Maskell argue that the co-existence of high levels of buzz and many pipelines ‘may provide firms located in outward-looking and lively clusters with a string of particular advantages not available to outsiders’(2004:31).

While it’s not possible to draw conclusions from Table 7.10 on the presence of ‘local buzz’ in any of the urban areas in which Irish high-technology businesses are located the results suggest that an urban location improves the probability of innovation. Combined with limited localised interaction with suppliers, customers and competitors this may suggest that business innovation is positively affected by a combination of certain elements of an urban location, or buzz, and long-distance, perhaps international, pipelines with suppliers, customers and competitors to acquire knowledge for innovation.

Overall, both models presented in Table 7.10 are significant. The likelihood ratio (LR) X^2 tests the hypothesis that there is no difference between the estimated model and the constant only model (i.e. that each coefficient is zero). The p-value in both cases is less than 0.05, which indicates that this hypothesis can be rejected at a 95% confidence level and the estimated models are significant indicators of the probability of product innovation and regular process innovation. Appendix 14 contains multicollinearity diagnostics that suggest multicollinearity is not a problem in this model and variances and standard errors are not overstated.

7.3.3 Summary Results and Conclusions

The purpose of this section is to test for localisation and urbanisation effects on innovation in Irish high-technology businesses. There is no support in the findings for a positive localisation effect on innovation in Irish high-technology businesses. An urban location, indicated by population density, has a positive effect on the probability of introducing new products. The policy implications of these results are discussed in detail in the next section.

7.4 Conclusions and Policy Implications

The results reported in this Chapter, which show a lack of evidence of localisation or cluster-based advantages for Irish high-technology businesses, have important policy implications. In Chapters 5 and 6 it was seen that interaction with customers and suppliers was frequent and significantly increased the probability of innovation. However, the analysis reported in this Chapter shows that this interaction does not occur locally or regionally. There is no evidence to suggest that geographic proximity increases the frequency of interaction with any of the interaction agents considered. Furthermore, there is no evidence of a positive effect on innovation of the agglomeration of similar businesses, referred to as localisation effects. There is some tentative evidence that an urban location improves the probability of product innovation.

It must be noted that the analysis presented above does not address all of the potential localisation and urbanisation economies from which businesses may benefit. The focus of this study is innovation and does not consider whether, for example, Irish businesses may benefit from lower costs associated with shared intermediate inputs and reduced likelihood of labour shortages and bottlenecks, or from an urban location by having access to municipal services and physical and communications infrastructure that are unavailable or are more expensive in rural areas. However, the results reported in this Chapter have clear implications for business-level innovation. These results do not provide evidence of localisation advantages for innovation in Irish high-technology businesses, though there is some support that an urban location does positively affect innovation.

Localisation advantages are based on the common location of businesses in the same industry. The two relevant sources of localisation advantages for innovation are knowledge spillovers through locally or regionally-based interaction and access to knowledge through a local thick skilled labour market. The absence of any evidence of local or regional interaction with suppliers, customers and competitors in the first two sections of this Chapter suggests that the former source of localisation advantage is not a feature of Irish high-technology sectors. In Table 7.6 it was seen that there is also no evidence of a significant labour market effect on the probability of being a product or regular process innovator.

The lack of support for localisation advantages for innovation in Irish high-technology businesses raises questions for the emphasis in Irish policy on cluster-based approaches to the development of innovative high-technology sectors. This emphasis is long-standing. The Culliton Report (1992) was the first to stress the importance of local or regional clusters around internationally competitive businesses for improved national competitiveness, and in particular for embedding foreign-owned businesses. These prescriptions were strongly influenced by the work of Porter (1990). The National Economic and Social Council subsequently commissioned research on the applicability of Porter's cluster approach to Ireland, which was somewhat critical (see for example, O'Malley and Van Egeraat, 2000). More recently, the National Competitiveness Council recommended support for clusters and networks (2004:3). Irish regional policy has also advocated a cluster-based approach to regional development. The National Spatial Strategy (Department of the Environment and Local Government, 2002) proposed an urban hierarchy model, consisting of eight gateways and nine hubs. It envisaged, for example, gateways as having "large clusters of national/international scale enterprises, including those involved in advanced sectors" (Department of Environment and Local Government, 2002:40).

The policy consensus on the importance of clusters and networks has been influenced, as in other EU countries, by the performance of particular industrial clusters, which have been associated with strong innovation performance, such as Silicon Valley, Emiglia-Romagna in Italy and the science-based cluster in Cambridge, UK (Forfás, 2004). These clusters have been highlighted by the work of authors such as Scott (1988), Porter (1990) and Castells and Hall (1994). The findings of this study however must call into question the suitability of a cluster-based approach, which is based on localisation advantages, in an Irish context. There are particular features of the Irish economy that undermine the applicability of this approach for Ireland. There has been a long-standing industrial policy of building competitive advantage on the back of foreign direct investment by successful high-technology businesses. Combined with the limited size of the Irish market this has had the effect of increasing the number of foreign based customers and suppliers and broadening the range of commercial contacts of Irish businesses in the high-technology sectors. Thus it is perhaps not surprising that the study finds that where interaction is strong between suppliers and customers it occurs over long distances.

The analysis above suggests that there may be a role for Irish regional policy in promoting business level innovation. However, the efforts within that policy to encourage related businesses to locate closer together in the hope of developing links may be misplaced. A more effective policy to support innovation in Irish high-technology businesses may be to improve accessibility for these businesses to businesses abroad and further away through investment in physical and communications infrastructure. Access to better and lower-cost infrastructure is a potential benefit of urban location (Parr, 2002).

The National Spatial Strategy (Department of the Environment and Local Government, 2002) was formulated as a response to increasing regional divergence, primarily caused by the impressive performance of the Greater Dublin Area. The analysis of urbanisation effects on Irish high-technology business innovation in this thesis indicates that businesses in the Greater Dublin Area do not have a greater probability of being product innovators than those in hubs and gateways identified in the NSS. However, businesses in urban areas are more likely to be product innovators than those located in less populous areas. This suggests that a regional structure based around agglomeration of businesses in several urban areas may support regional growth and competitiveness based in those areas. This provides support for that element of the NSS approach that stresses urban gateways as drivers of regional economic. However, the NSS maintains the policy emphasis on localisation advantages by stating that each gateway will be characterised by clusters of internationally competitive businesses. The results of this study tentatively suggest that innovation performance in high-technology businesses' may be promoted not by encouraging similar businesses to locate in the same region but by encouraging a diversity of businesses and skills in an urban setting. These results pose difficult problems for regional and innovation policy makers.

The significant positive effect of urban agglomeration, measured by population density, on the probability of product innovation, also has implications for the distribution of economic activity. Since there is some evidence of a positive effect on business innovation of urban location, a policy that seeks to distribute activity across a wider area will have a detrimental effect on the innovation and, in turn, competitive performance of Irish regions.

Chapter 8 : Conclusion: Summary of Findings, Policy Implications and Future Research Agenda

The objective of this thesis has been to answer two critical questions for the continuing economic development of the Irish economy. These questions are set out at the start of Chapter 1. The first question is what drives innovation in Irish high-technology businesses. In particular the study is concerned with the relative importance of interaction among businesses and/or between businesses and other institutions as a source of knowledge for innovation. The second question is concerned with the extent to which these interactions are locally or regionally based. The thesis uses original data from a specially designed survey of businesses in the Irish high-technology sectors to address these questions.

New indicators of process innovation output, interaction with businesses and other institutions and geographic proximity are developed in order to test hypotheses related to the importance of interaction as a source of knowledge for innovation and the extent to which interaction is geographically bounded. An innovation production function approach is used to estimate, based on survey data, the relative importance of internal and external sources of knowledge for innovation. In addition, secondary data on population densities, educational standards and labour skills in Irish regions are used to test the effect of agglomeration on innovation in Irish high-technology businesses.

The purpose of this Chapter is to draw together the main findings of this thesis, consider the policy implications and suggest fruitful areas for future research in the area. It is structured as follows. The first section outlines the contents of the empirical Chapters. The second section summarises the findings. Conclusions based on these findings are considered in the second section along with the more salient enterprise, innovation and regional policy implications. The final section considers limitations of the current study and the opportunities that these and the findings of the study present for fruitful further research.

8.1 Summary of Findings

The following are the main findings that emerge from the analyses in Chapters 5 to 7.

Chapter 5 presents a descriptive statistical analysis of the survey results. This analysis shows that R&D is performed by 122 (67%) businesses. Higher incidence of R&D is found among indigenous and younger businesses. Also, product innovators and regular process innovators are significantly more likely to perform R&D than non-innovators.[2]

With regard to external sources of knowledge it is found that interaction for the purposes of both product and process innovation is strong between high-technology businesses and other group companies, suppliers and customers. This is indicated by the finding that, on average, interaction is regular, frequent or continuous with these

[2] See Table 5.17 (page 182), Table 5.18 (page 183), Table 5.21 (page 187) and Table 5.22 (page 188).

agents for 81% of businesses.[3] This strong interaction with other group companies, suppliers and customers occurred over long distances as indicated by the average driving time from high-technology businesses to the most important of these agents being greater than 4 hours in 67% of cases.[4] This indicates that such interaction does not occur locally or regionally within Ireland and may be international. Interaction for both product and process innovation with competitors, academic-based researchers and innovation-supporting agencies is weak, with 64% of businesses rarely or never interacting with these interaction agents in the promotion of product innovation. Where interaction occurs with academic-based researchers and innovation-supporting agencies it is spread between local, regional and more distant agents.[5]

The inferential analysis begins in Chapter 6 by estimating innovation production functions. It is found that the frequency of interaction with customers has the strongest significant positive effect on the probability of being a product innovator. This is followed by the frequency of interaction with suppliers and innovation-supporting agencies. Whether a business engages in R&D is also significantly positively associated with the probability of being a product innovator. A particularly interesting finding is that the frequency of interaction with academic-based researchers is negatively associated with the probability of being a product innovator.[6] All other variables directly related to innovation activity are found to be insignificant in terms of their contribution to the explanatory power of the estimation, which itself is notable.

[3] See Table 5.27 (page 195)
[4] See Table 5.29 (page 198)
[5] See Table 5.33 (page 204)
[6] See Table 6.4 (page 237)

Two alternative measures of product innovation are considered, innovation intensity, as measured by the number of new products introduced per 100 employees, and innovation success, measured by the share of turnover attributable to newly introduced products. For both these estimations the interaction variables are found to be less important indicators. For innovation intensity interaction with customers is the only significant interaction variable.[7] The diversity of interaction is found to be positively associated with innovation success. However, this is found to be more strongly associated with spending in excess of 10% of turnover on R&D .[8]

Just as with product innovation, the probability of being a regular process innovator is positively associated with the frequency of interaction with customers and suppliers, though their relative importance is reversed. In this case the frequency of interaction with suppliers has a greater marginal effect. Whether a business performs R&D has the greatest marginal effect on the probability of regular process innovation. Once again, the frequency of interaction with academic-based researchers is found to be negatively associated with the probability of regular process innovation.[9] Process innovation is also measured on a frequency scale and the probability of more frequent process innovation is positively associated with both the diversity of interaction and whether the business engages in R&D.[10]

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[7] See Table 6.5 (Page250)
[8] See Table 6.6 (page 253)
[9] See Table 6.7 (page 258)
[10] See Table 6.8 (page 264)

A greater proportion of businesses that interact with customers over longer geographic distances are product innovators. The frequency of interaction with customers for product innovation is independent of geographical distance. There is no evidence that the frequency of interaction with customers and suppliers for process innovation is greater over shorter distances.[11] A significant negative relationship between the frequency of interaction with suppliers and geographical proximity, indicating that businesses tend to talk over greater distances with suppliers in relation to process innovation.[12]

The probability of being a product innovator is positively associated with an urban location, as measured by the density of population.[13]

8.2 Research Conclusions - Implications for Policy and Business

These results have important implications that merit debate in policy circles which are discussed in this section. These implications are also considered in Jordan and O'Leary (2005). This section also presents some implications for businesses in Irish high-technology sectors arising from this thesis.

Policy Implications

The results indicate the absence of strong interaction for the purpose of promoting product and process innovation in Irish high-technology businesses between locally or

[11] See Table 7.1 (page 282) and Table 7.3 (page 288)
[12] See Table 7.2 (page 286)
[13] See Table 7.10 (page 327)

regionally based concentrations of suppliers, customers, competitors, academic-based researchers and innovation-supporting agencies.

The results provide support for policy emphasis on the promotion of networks and interaction among businesses to encourage innovation. For instance, Forfás states that there should be a "focus on inter-business networks as a key building block for the development of innovation capacity" (2004:7). This study's findings show that interaction among businesses and/or between businesses and innovation-supporting agencies is a significant source of knowledge for innovation in Ireland's high-technology sectors. However the results indicate that interaction with all interaction agents is not equally important. Interaction with customers and suppliers is positively associated with the probability of being a product innovator and a regular process innovator. Interaction with customers is more important for product innovation, suggesting that businesses learn of market opportunities for new products through customer interaction. On the other hand, interaction with suppliers is more important for process innovation, which suggests that new processes may be tied to the adoption of new sources of supply or new equipment.

There is little evidence of widespread interaction between competitors in the high-technology sectors and there is no discernible relationship between this form of interaction and the probability of product and process innovation. The notion of collaboration between competitors has arisen from a number of celebrated examples in places such as Silicon Valley, Emiglia-Romagna and Cambridge (Scott, 1988, Castells and Hall, 1994 and Forfás, 2004), where the businesses are small and flexible, thus enabling alliances to form easily. These special cases may not be easily generalised (Gordon and McCann, 2005) and may not necessarily be replicated in an Irish context. The lack of interaction between competitors in high-technology sectors in Ireland may reflect the particular features of the Irish economy. Typically high-technology businesses located in the country are a mix of very large foreign-owned and smaller indigenous businesses, operating in particular international market niches, with few competing with each other.

This thesis finds that there is weak interaction for innovation between high-technology businesses and academic-based researchers. Furthermore it is found that interaction with academic-based researchers is negatively associated with the probability of product and process innovation in Irish high-technology businesses. The implications of this finding for Irish enterprise and innovation policies are discussed in detail in the final section of Chapter 6. These findings are timely in light of the sizeable public investment to date in third-level research and the Irish government's recent commitment to substantial public funding of R&D in coming years (Department of Enterprise Trade and Employment, 2006). An essential element of Irish government's *Strategy for Science, Technology and Innovation to 2013* is the investment of €2.7bn on scientific research in the period to 2008 (Department of Enterprise Trade and Employment, 2006). A sizeable portion of this spending will be invested in research in third-level institutions. A critical factor for the success of this funding in promoting innovative enterprises is interaction between businesses and third-level researchers. If, as this study indicates, high-technology businesses interact only weakly with academic-based researchers and that interaction does not increase the probability of innovation, the question arises as to whether the return to Ireland from this public investment is likely to be satisfactory.

It is found that performing R&D within a business has a positive effect on the likelihood and intensity of both product and process innovation. Measures to increase business level R&D should raise the level of innovation output in the high-technology sector. This finding, in combination with the finding on the effect of interaction with academic-based researchers on innovation in businesses, suggests that policy makers should be clearly targeting research funding and support towards R&D in businesses. The greater emphasis placed by the Enterprise Strategy Group on the funding of applied research and in-business research and development (2004: 69) indicates some cognizance of the importance of developing connectivity between third-level institutions and businesses. Although the return from substantial actual and planned public funding of research and development may be long-term, it can be inferred from the results presented here, that the level and nature of the existing interaction between these businesses and third-level institutions may seriously compromise the achievement of satisfactory future returns.

The final interaction agent is innovation-supporting agencies, which is found to be significantly positively associated with the probability of product and process innovation. The finding that most interaction with suppliers and customers occurs over further distances, and probably internationally in many cases, may explain the positive effect of interaction with innovation-supporting agencies for innovation in Irish high-technology businesses, as it may reflect the role, for example, of Enterprise

Ireland in assisting the development of links between Irish businesses and international customers.

A critical element of policy attempts to develop and support networks and interaction in Irish businesses is the role of geographic proximity, which is considered an important conduit of interaction. However, despite repeated efforts devoted to building linkages locally and regionally among businesses and between businesses and other institutions, especially between foreign-owned and indigenous businesses, it is notable that this study finds interaction for innovation between high-technology businesses and customers and suppliers occurs over long distances.

Irish policymakers' views of interaction occurring within geographical clusters has been influenced by the work of authors such as Scott (1988), Porter (1990) and Castells and Hall (1994). From the perspective of innovation, Gordon and McCann (2005) have argued that these are an idealized type of cluster, which may not always be superior to alternative forms of agglomeration. The lack of local or regional interaction emerging from this study may reflect the particular characteristics of the Irish economy. There has been a long-standing industrial policy of building competitive advantage on the back of foreign direct investment by successful high-technology businesses. Combined with the limited size of the Irish market this has had the effect of increasing the number of foreign based customers and suppliers and broadening the range of commercial contacts of Irish businesses in the high-technology sectors. Thus it is perhaps not surprising that the study finds that interaction is strong and occurs between these businesses and other group companies over long distances. These findings raise questions about the particular type, if any, of local/regional clusters and networks, which might reasonably be expected for the promotion of innovation in Irish high-technology businesses.

Given the importance of innovation, the lack of local and regional linkages among high-technology businesses is a cause for concern, especially in the context of continued public funding devoted to developing networks and clusters. This finding casts doubt on attempts to build clusters of businesses within these sectors, at least to the extent that well-known clusters abroad may be imitated. Policies to develop local and regional interaction in businesses within these sectors must recognise the particular characteristics of the Irish economy.

Moreover, since these businesses are currently interacting with other businesses over longer distances or probably abroad suggests that efforts to encourage related businesses to locate closer together in the hope of developing links may be misplaced. A more effective policy may be to improve accessibility for Irish businesses to businesses abroad and further away through investment in physical and communications infrastructure.

There is evidence that businesses in urban agglomerations are more likely to be product innovators. This may indicate that there are urbanisation economies in relation to innovation at the business level. Thus for example, in the Irish case more attention may need to be devoted to urbanisation economies, which depend on a diversity of businesses and skills in an urban setting. In the first instance this requires research to be undertaken to investigate the issue.

Interaction is a less important indicator of product innovation intensity and success. This indicates that interaction may support businesses to overcome initial barriers to introducing a new product but does not contribute to increasing the scale of product innovation output. Internal resources may be more important in this subsequent phase of business innovation activity.

Overall, the survey results suggest a limited role for geographical proximity in regard to innovation by Irish high-technology business. This may be partly due both to the distinctive development of Ireland's internationally competitive industry, with the dominance by foreign-owned businesses, and to the small size of the country. However, it may also be attributable to Ireland's undeveloped regional innovation systems, which currently seem to have little to offer these businesses in pursuit of enhanced innovation performance. Given the agreed imperative of developing alternative urban centres to the greater Dublin area, the failure to decentralize power regionally may undermine the ability of Ireland's other major urban centres to use 'joined-up' government in order to address these deficiencies.

In order to develop stronger innovation systems, Irish regions require realistic policies targeted at facilitating interaction between businesses and regionally based suppliers, third-level institutions and support agencies. A clear implication of the survey results is the need to also facilitate national and, more crucially, international interactions by

Irish-based business. Thus, policies to address the transport and communications infrastructure deficits, which policymakers often fail to connect to innovation, may have a crucial role in improving the innovation performance of Irish regions by facilitating interaction over long distances. It should not be taken for granted that policy is to be focused on high-technology clusters as the presence of urbanisation economies may warrant support for a diverse range of industries and services. The new emphasis on the funding of PhD's in Ireland's new 'fourth level' may very well yield a disappointing return. It may also result in the more 'basic' educational and training needs of the Irish workforce, which were important during the 'Celtic Tiger' boom, being undermined.

Clearly public funding of research and development in third-level institutions and of clusters or networks to support high-technology business should only be committed if the return is justified following detailed analysis of economic costs and benefits.

Implications for Business

The results of this study have important implications for businesses in Irish high-technology sectors that are seeking to increase their levels of innovation.

First, there is a significantly positive relationship between performing R&D and the probability of innovation, both product and process. Businesses that engage in R&D are more likely to develop and market new and improved products and processes. This suggests businesses should perform R&D if they wish to improve their chances of innovating. An important qualification in this regard though is the lack of any support for a relationship between the incidence or intensity of innovation and the existence of a dedicated R&D department with a business. It appears that businesses that successfully innovate have a less formal or less routine approach to R&D than may be expected in a dedicated R&D function.

Second, the results strongly indicate that the knowledge for innovation is often found outside the business. The frequency of interaction, particularly with customers and suppliers, is positively associated with the level of innovation in the business. This suggests that businesses must not be insular in their attitudes towards innovation opportunities. The knowledge for innovation may reside outside the business and/or the means of getting a new product or process to the market successfully may require interaction with, say, customers in regard to their needs and suppliers with regard to the equipment or services they can provide.

This study finds that interaction with suppliers, customers and innovation supporting agencies is an important source of knowledge for innovation. However, there is no evidence that this interaction is occurring on a local or regional basis. The frequency of interaction with an interaction agent is independent of their geographic proximity. This indicates that businesses are interacting for innovation with those interaction agents they perceive as adding greatest value to innovation activity, rather than interacting with agents because they are nearer. This means that businesses should be unconvinced by arguments for a cluster-based effect in relation to *innovation* in Ireland. Concentrating businesses in similar sectors geographically does not significantly improve the probability of more frequent interaction or the probability of innovation in those businesses.

Furthermore, if businesses are more likely to benefit, in terms of innovation, from interaction with suppliers and customers that may be located further away, it is important that access to those customers and suppliers is made easier. This requires improved transport and telecommunications infrastructure. The perceived primary benefit to business of improved infrastructure has traditionally been to provide lower costs to market or supplies. This study suggests that improved infrastructure is also important to businesses in the so-called 'knowledge economy' to facilitate the sharing of ideas and knowledge for innovation. Businesses have a role in lobbying for improved physical and telecommunications infrastructure, not just to transport goods but also people and their knowledge.

8.3 Future Research Agenda

The findings of this study indicate that more research should be undertaken on these important issues. Larger and more detailed surveys and case study research are required on how high-technology businesses interact with agents and, perhaps more importantly, how third-level institutions, innovation support agencies and locally-based suppliers interact with these businesses. In addition research is required to determine the relative importance of industry clusters and urbanisation economies in Irish urban areas. The overriding objective of further research must be to identify realistic policies to improve local/regional interaction in Irish regions and/or improve accessibility between Irish high-technology businesses and their distant or international interaction agents.

The methodology used in this thesis could fruitfully be used to analyse data from a larger survey of Irish businesses. Such a survey would include businesses from a wider range of sectors, including traditional manufacturing and service sectors. It is reasonable to expect that there are different factors driving innovation in businesses in different sectors. Also, where there are common factors across sectors, their relative importance may differ. The role of geographical proximity may vary according to the degree to which businesses operate in internationally traded sectors. Such detailed sectoral analysis would improve policy effectiveness by enabling more targeted initiatives based on sectoral requirements.

Such a large-scale study could be undertaken over a number of years to provide longitudinal data. The benefits of such a data set would be to benchmark future policies targeted at business-level innovation, to identify factors that alter over time in their importance as drivers of business level innovation and also to provide survey-based data on levels of innovation within the Irish economy. The inadequacies of standard measures of innovation activity, such as R&D expenditure and patents, are discussed in detail in section 3.5 of Chapter 3. There has been an increase in the use of survey-based measures of business innovation by European policy-makers, most notably the use of results from the Community Innovation Survey to generate the Innovation Scoreboard published by the European Commission. The Community Innovation Survey is an EU wide survey of business innovation using standard measures and is conducted every three years. It is to be welcomed that the Community Innovation Survey has been published for the first time for Ireland in 2006 (Forfás, 2006).

While a larger database on business level innovation would facilitate a greater breadth of analysis in this area, there is also scope for greater depth of analysis of the nature of innovation in Irish businesses. This would require gathering qualitative data on the innovation activities of selected businesses, through the use of case study research. A case study approach involves a contextual analysis providing richer and more detailed data. Such case study research would be very beneficial in an area as complex as the process of innovation, particularly in relation to interaction for innovation, which takes many and diverse forms. For example, this study measures the incidence and frequency of interaction among businesses and between business and other institutions, while case study research could explore the nature of these interactions, including whether they are intentional or accidental, market or non-market-mediated, formal or informal and sectorally, regionally or technologically based. This work could shed further light on the findings of this study, such as the lack of interaction with competitors and the negative relationship between interaction with academic-based researchers and business innovation. As noted earlier, the latter finding has very important implications for the success of current substantial public funding of research, and there is a pressing need for more detailed qualitative analysis of the nature of interaction between business and third-level institutions.

Another valuable contribution that may be made to the study of innovation is an international study of the drivers of business-level innovation. As noted earlier, at EU level the Community Innovation Survey gathers data on innovation activity in member states. However, the Community Innovation Survey does not consider some of the key aspects of the drivers of innovation included in this thesis, such as interaction as a source of innovation or geographic proximity. It would be worthwhile to extend the survey used in this thesis to an international study, which could focus on particular regions in different countries. It was argued earlier that the widely celebrated examples of geographic clusters of innovation, such as Silicon Valley and Cambridge, may not be easily imitated elsewhere because of specific regional or national characteristics. An international comparison study would shed light on regional differences and similarities to allow regional policy-makers adopt aspects of other regional models that may be suitable to their own situations.

In Chapter 6 an innovation production function model is presented and estimated using five innovation output measures as the dependent variable. In these models innovation output at the business level is modelled as being a function of R&D effort within the business and the incidence or frequency of interaction for innovation with a range of potential interaction agents, while controlling for several business characteristics, such as size, age and nationality. Diagnostic tests on these estimations showed no statistical evidence of endogeneity within the model. However, it is possible that innovation output, R&D and interaction for innovation may be interdependent. For example, Cohen and Levinthal (1990) argue that R&D increases a business' absorptive capacity, which enables a business to more easily identify, evaluate and exploit external knowledge. Therefore, a business may be more likely to interact with all or certain specific interaction agents if they are already engaged in R&D. Also, businesses that interact for innovation may be expected to engage in R&D where they are interacting for innovation with other businesses engaged in R&D or with academic-based researchers. It may be worthwhile therefore to undertake simultaneous equation analysis using the current data to further probe the findings of this study.

The analysis at the end of Chapter 7 is intended to shed light on the importance of urbanisation economies for innovation in Irish businesses. Irish innovation policies to date have stressed the importance of interaction within local or regional clusters of related businesses as a source of knowledge for innovation. This latter approach can be characterized as emphasising localisation economies, where businesses benefit from an agglomeration of businesses in the same or related sectors. These benefits may be based on shared intermediate inputs, a thick labour market and/or knowledge spillovers. Further research is now required to determine the relative importance of urbanisation economies in Irish urban areas. These economies may be derived from diversity of skills, ideas and cultures and/or a more permissive environment, which facilitate more and broader combinations of knowledge and greater opportunity for new and varied ideas to surface and reach the market.

It is clear that the findings of this study raise important issues for Irish enterprise, innovation and regional policies and that the methods adopted provide a useful framework for analysing these areas of considerable policy importance.

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APPENDIX 1

SURVEY QUESTIONNAIRE AND COVER LETTER

Date

Survey on Innovation in Irish Industry

Dear Mr. **__________**,

I contacted your office earlier today regarding a study being undertaken in the Department of Economics but unfortunately missed you.

Innovation is a critical aspect of business success and is a key source of future Irish competitiveness. However, there is a lack of quantitative information on what drives innovation in Irish industry and why some businesses are more innovative than others.

We would appreciate your assistance in shedding light on this very important question by completing the attached questionnaire on innovation in your business. The questionnaire will form the basis of a study, funded by Enterprise Ireland, to investigate the factors that drive innovation in Irish industry. This study will shed light on the relative roles played by R&D effort, interaction between businesses, universities and publicly funded institutions in explaining the innovation performance of Irish businesses, allowing these businesses to learn more about themselves and their sectors.

A comprehensive report on the findings of the study will be prepared specifically for respondents to the survey and will be circulated later this year.

It should also be noted that the study has important implications for industrial, innovation and regional policy in Ireland. This is an ***opportunity for your business to contribute to the development of policy in these areas for the future.*** Responses are treated with the ***strictest confidence.***

It is estimated that the questionnaire will take 10 to 15 minutes to complete. You can return the completed questionnaire using the enclosed stamped addressed envelope. Alternatively, if you prefer, you can access a soft copy of the questionnaire at http://www.ucc.ie/ucc/depts/economics/staff/academic/djordan.html, which can be downloaded and emailed back to d.jordan@ucc.ie. If you have any queries please contact Declan Jordan at the same email address or by calling 021 – 4902097. Thank you in advance for your time.

Yours sincerely,

Eoin O'Leary.

Declan Jordan   Dr Eoin O’Leary

Innovation in Irish Industry

Respondent's Name:	
Respondent's Position:	
Business Name:	
Business Address:	
Telephone:	
Email:	

Please indicate whether you would like to receive the report on the findings of this survey by:

Hard Copy (Post) ☐ Soft Copy (email) ☐

Instructions

The questionnaire refers to your business. If your business is a parent or a subsidiary company the questionnaire should be completed only for your business, and not related companies.

The questions refer to the innovative activity of your business for the three years from the start of 2001 to the end of 2003.

We realise that some questions may request potentially sensitive information. All responses will be treated with absolute confidentiality.

Please answer each question. If you require clarification in relation to any question please contact Declan Jordan on 021 4902097 or at d.jordan@ucc.ie.

Section A – Characteristics of Your Business

A.1. Which of the following best describes your business? *(Please tick one box)*

A stand-alone business ☐
A parent or group HQ ☐
A subsidiary in a group ☐
Other ☐

A.2. If your business is a subsidiary, in what country is the group's HQ located?

____

A.3. In what year did your business begin operations in Ireland? ☐

A.4. How many products/services did your business offer to the market at the end of 2003? ☐
(For example, if your business offers two types of pens and three types of paper, then the total number of products is five)

A.5. How many employees did your business have

(a) at the start of 2001? ☐

(b) at the end of 2003? ☐

(Please estimate in terms of full-time equivalent e.g. two half-time employees is equivalent to one full-time employee)

A.6. Please estimate the percentage of your workforce who have a third level degree (or similar technical qualification) as their highest qualification. ☐ %

A.7. Please indicate your business net profit as a percentage of turnover in 2003. (Please tick one box)

Not in Profit	☐	21% to 30%	☐
0 to 10%	☐	31% to 40%	☐
11% to 20%	☐	41% to 50%	☐

A.8. Please indicate your business' rate of growth in sales between 2001 and 2003. (Please tick one box)

Decline	☐	51% to 60%	☐
0 to 10%	☐	61% to 70%	☐
11% to 20%	☐	71% to 80%	☐
21% to 30%	☐	81% to 90%	☐
31% to 40%	☐	91% to 100%	☐
41% to 50%	☐	Greater than 100%	☐

Section B – Innovation in Your Business

There are two types of innovation: **product innovation** and **process innovation.**

Product innovation is the introduction to the market of a new good or service, of which buyers had not previously been aware, or the introduction to the market of an improved version of an existing good or service. This new version may include additional features or improved functionality.

B.1. How many new goods/services has your business introduced to the market between 2001 and 2003? ☐
(If your business has not introduced any please answer '0', please skip Question B.2.)

B.2. Approximately, what percentage of turnover in 2003 was generated by the goods/services identified in Question B.1.? ☐ %

Process innovation is introduced to achieve improved efficiency, lower costs and/or higher profitability. It may include

(v) the introduction of a new method of production of existing goods or method of delivery of existing services,
(vi) the re-organisation of support activities, management structures or distribution channels,
(vii) the introduction of existing goods and/or services to new markets and
(viii) the introduction of a new source of supply of materials or other inputs.

B.3. Please indicate the extent to which your business introduced new processes between 2001 and 2003. (Please tick one box)

Continuously	**Frequently**	**Regularly**	**Rarely**	**Never**
☐	☐	☐	☐	☐

Please continue with the questionnaire even if you have not introduced new products or processes in the three years between 2001 and 2003.

Section C – Sources of Innovation

There are four possible sources of product and/or process innovation;
(i) Research and Development (R&D) by your business,
(ii) Interaction with other businesses, such as suppliers, customers and competitors,
(iii) Interaction with academic-based researchers and
(iv) Interaction with innovation supporting agencies, which are publicly funded institutions (for example Enterprise Ireland) that support R&D in firms, through research grants and facilitating interaction.

Interaction may involve meetings, networking or other communications that affect innovation in your business. Interaction may range from social or informal, perhaps unintentional, networking to formal or contractual collaboration that generates new knowledge used in product and/or process innovation.

Academic-based researchers are those based at third level institutions, such as Universities or Institutes of Technology, or at university-based research centres.

R&D Activity.

C.1. Did your business undertake R&D between 2001 and 2003?

Yes ☐
No ☐ *(If not please skip to question C.6.)*

C.2. Did your business have a dedicated R&D department at any time between 2001 and 2003?

Yes ☐
No ☐ *(If not please skip to question C.4.)*

C.3. How many people were employed in the R&D department on average between 2001 and 2003? ☐
(Please estimate part-time employees in terms of full-time equivalent)

C.4. Please estimate R&D expenditure as a proportion of your business' turnover between 2001 and 2003. (Please tick one box)

0 to 5%	☐	16% to 20%	☐
6% to 10%	☐	21% to 25%	☐
11% to 15%	☐	More than 25%	☐

C.5. Please indicate approximately how much financial support for R&D from innovation supporting agencies your business received as a proportion of total R&D expenditure between 2001 and 2003. *(Please tick one box)*

Did not receive funding	☐	11% to 15%	☐
0% to 5%	☐	16% to 20%	☐
6% to 10%	☐	More than 20%	☐

C.6. If your business is a parent or subsidiary company, did any other business within your group have a dedicated R&D department at any time between 2001 and 2003?

Yes ☐

No ☐

N/A ☐

C.7. Is your business a member of a Business Association or Industry Lobby Group?

Yes ☐

No ☐

Interaction

C.8. Please indicate the frequency with which you have interacted with the following (whether formally or informally) in relation to product innovation in your business between 2001 and 2003. (If your business did not interact with any of the following in relation to product innovation, please tick 'Never')

	Continuous	**Frequently (Several Times a Year)**	**Regularly (At least once a year)**	**Rarely (Less than Once a Year)**	**Never**
Parent and subsidiary companies	☐	☐	☐	☐	☐
Suppliers of Equipment, Materials and/or Services	☐	☐	☐	☐	☐
Customers	☐	☐	☐	☐	☐
Competitors	☐	☐	☐	☐	☐
Academic-Based Researchers	☐	☐	☐	☐	☐

Innovation-Supporting Agencies	☐	☐	☐	☐	☐

C.9. For each category below, please determine the most important source of knowledge for your business' product innovation and estimate the average driving time (one-way) from your business. (Where the relevant source of knowledge for any category is based outside of Ireland please answer '> 4 Hours')

	Not Applicable	**< ½ Hour**	**½ to 1 Hour**	**1 to 2 Hours**	**2 to 4 Hours**	**>4 Hours**
Parent or subsidiary company	☐	☐	☐	☐	☐	☐
Supplier of Equipment, Materials and/or Services	☐	☐	☐	☐	☐	☐
Customer	☐	☐	☐	☐	☐	☐
Competitor	☐	☐	☐	☐	☐	☐
Academic-Based Researcher	☐	☐	☐	☐	☐	☐
Innovation-Supporting Agency	☐	☐	☐	☐	☐	☐

C.10. Please indicate the frequency with which you have interacted with the following (whether formally or informally) in relation to process innovation in your business between 2001 and 2003. (If your business did not interact with any of the following in relation to product innovation, please tick 'Never')

	Continuous	**Frequently (Several Times a Year)**	**Regularly (At least once a year)**	**Rarely (Less than Once a Year)**	**Never**
Parent and subsidiary companies	☐	☐	☐	☐	☐
Suppliers of Equipment, Materials and/or Services	☐	☐	☐	☐	☐
Customers	☐	☐	☐	☐	☐
Competitors	☐	☐	☐	☐	☐

Academic-Based Researchers	☐	☐	☐	☐	☐
Innovation-Supporting Agencies	☐	☐	☐	☐	☐

C.11. For each category below, please determine the most important source of knowledge for your business' process innovation and estimate the average driving time (one-way) from your business. (Where the relevant source of knowledge for any category is based outside of Ireland please answer '> 4 Hours')

	Not Applicable	**< ½ Hour**	**½ to 1 Hour**	**1 to 2 Hours**	**2 to 4 Hours**	**> 4 Hours**
Parent or subsidiary company	☐	☐	☐	☐	☐	☐
Supplier of Equipment, Materials and/or Services	☐	☐	☐	☐	☐	☐
Customer	☐	☐	☐	☐	☐	☐
Competitor	☐	☐	☐	☐	☐	☐
Academic-Based Researcher	☐	☐	☐	☐	☐	☐
Innovation-Supporting Agency	☐	☐	☐	☐	☐	☐

Section D – Your Business' Competitive Environment

D.1. Please rate the importance of **product innovation** as a source of competitive advantage for your business.

Not Important			Neutral			Very Important
1☐	2☐	3☐	4☐	5☐	6☐	7☐

D.2. Please rate the importance of **process innovation** as a source of competitive advantage for your business.

Not Important			Neutral			Very Important
1☐	2☐	3☐	4☐	5☐	6☐	7☐

D.3. Please indicate the extent to which you agree with the following statements in relation to the market for your principal products and/or services.

Competition is intense in all aspects (price, quality, service etc.)

Strongly Disagree 1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐ Strongly Agree

Businesses compete mostly on price.

Strongly Disagree 1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐ Strongly Agree

Businesses compete mostly on product quality or specifications.

Strongly Disagree 1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐ Strongly Agree

Thank you very much for completing this survey.

Please return the completed questionnaires using the stamped addressed envelope that is enclosed.

APPENDIX 2

SURVEY QUESTIONNAIRE CODING AND VARIABLE DESCRIPTIONS

APPENDIX 3

FREQUENCY OF INTERACTION FOR PRODUCT INNOVATION BY SECTOR AND OWNERSHIP FOR EACH INTERACTION AGENT

Tables A3.1 to A3.6 present the frequency of interaction in relation to product innovation with each interaction agent by sector and ownership. First, the frequency of interaction for product innovation with group companies is shown in table A3.1.

Table A3.1 – Frequency of Interaction with Group Companies for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			Ownership[3]	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	2 (6%)	5 (14%)	0 (0%)	5 (25%)	2 (2%)
Rarely	0 (0%)	3 (9%)	1 (3%)	1 (5%)	3 (4%)
Regularly	2 (6%)	1 (3%)	4 (12%)	4 (20%)	3 (4%)
Frequently	11 (32%)	6 (17%)	11 (33%)	4 (20%)	24 (30%)
Continuously	19 (56%)	20 (57%)	17 (52%)	6 (11%)	50 (61%)
Total	34 (100%)	35 (100%)	33 (100%)	20 (100%)	82 (100%)

Notes:

1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square =12.823, df=8, p-value = 0.118. 9 cells (60%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square =21.568, df=4, p-value = 0.000. 4 cells (40%) have an expected count less than 5.

There is no evidence of a divergence in the frequency of interaction by sector ($p>0.025$), though, as suggested in Table 5.24 for the incidence of interaction, there is a greater frequency of interaction with other group companies among foreign-owned businesses ($p<0.025$).

Table A3.2 presents the frequency of interaction with suppliers for product innovation by sector and ownership.

Table A3.2 – Frequency of Interaction with Suppliers for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			Ownership[3]	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	5 (7%)	16 (25%)	2 (5%)	12 (12%)	11 (13%)
Rarely	5 (7%)	2 (3%)	3 (7%)	7 (7%)	3 (4%)
Regularly	20 (27%)	14 (22%)	8 (19%)	27 (28%)	15 (17%)
Frequently	27 (36%)	17 (26%)	21 (49%)	27 (28%)	39 (45%)
Continuously	18 (24%)	16 (25%)	9 (21%)	25 (26%)	18 (21%)
Total	75 (100%)	65 (100%)	43 (100%)	98 (100%)	86 (100%)

Notes:
1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square =17.567, df=8, p-value = 0.025. 3 cells (20%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square =7.643, df=4, p-value = 0.106. 1 cell (10%) has an expected count less than 5.

The null hypothesis of equality across sectors in the frequency of interaction is rejected at a 95% level of confidence ($p<0.025$). This indicates that businesses in the *Chemicals and Pharmaceuticals* sector have a higher frequency of interaction with suppliers for product innovation; 49% interact frequently and 21% interact continuously. The *ICT* sector displays the lowest frequency of interaction with this interaction agent; 25% did not interact with suppliers. There is no evidence of a difference between ownership types.

Table A3.3 presents the frequency of interaction with customers for product innovation.

Table A3.3 – Frequency of Interaction with Customers for Product Innovation by Sector and Ownership number of respondents (percentages in parentheses[1])

	Sector[2]			**Ownership[3]**	
Frequency[1]	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	4 (5%)	6 (9%)	2 (5%)	5 (5%)	7 (8%)
Rarely	3 (4%)	0 (0%)	3 (7%)	4 (4%)	2 (2%)
Regularly	10 (14%)	6 (9%)	9 (21%)	12 (12%)	13 (16%)
Frequently	28 (38%)	20 (31%)	15 (35%)	30 (31%)	33 (39%)
Continuously	29 (39%)	32 (50%)	14 (33%)	47 (48%)	29 (35%)
Total	74 (100%)	64 (100%)	43 (100%)	98 (100%)	84 (100%)

Notes:

1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square =10.095, df=8, p-value = 0.258. 6 cells (40%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square =4.395, df=4, p-value = 0.355. 2 cells (20%) have an expected count less than 5.

There is no evidence in Table A3.3 of a difference across sectors and ownership type in the frequency of interaction with customers. In both cases the chi-square probability value is greater than 0.025. This is also the case in Table A3.4, which refers to the frequency of interaction for product innovation with competitors.

Table A3.4 – Frequency of Interaction with Competitors for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			Ownership[3]	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	28 (38%)	27 (42%)	19 (44%)	33 (34%)	42 (50%)
Rarely	21 (29%)	15 (23%)	14 (33%)	28 (29%)	22 (26%)
Regularly	13 (18%)	13 (20%)	8 (19%)	21 (21%)	13 (16%)
Frequently	10 (14%)	5 (8%)	2 (5%)	12 (12%)	5 (6%)
Continuously	1 (1%)	5 (8%)	0 (0%)	4 (4%)	2 (2%)
Total	73 (100%)	65 (100%)	43 (100%)	98 (100%)	84 (100%)

Notes:

1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square = 9.991, df=8, p-value = 0.271. 4 cells (27%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square =6.191, df=4, p-value = 0.185. 2 cells (20%) have an expected count less than 5.

Table A3.5 shows the frequency of interaction for product innovation with academic-based researchers and Table A3.6 shows the frequency for innovation-supporting agencies. The null hypotheses of equality in the frequency of interaction across sectors and ownership types for each interaction agent cannot be rejected (p>0.025).

Table A3.5 – Frequency of Interaction with Academic-Based Researchers for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			Ownership[3]	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	24 (33%)	34 (53%)	14 (33%)	41 (42%)	32 (39%)
Rarely	23 (32%)	13 (20%)	13 (30%)	23 (24%)	26 (31%)
Regularly	13 (18%)	12 (19%)	8 (19%)	16 (16%)	17 (21%)
Frequently	11 (15%)	4 (6%)	6 (14%)	15 (15%)	6 (7%)
Continuously	2 (3%)	1 (2%)	2 (5%)	3 (3%)	2 (2%)
Total	73 (100%)	64 (100%)	43 (100%)	98 (100%)	83 (100%)

Notes:

1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square = 9.465, df=8, p-value = 0.305. 3 cells (20%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square = 4.166, df=4, p-value = 0.384. 2 cells (20%) have an expected count less than 5.

Table A3.6 – Frequency of Interaction with Innovation-Supporting Agencies for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			Ownership[3]	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	24 (32%)	22 (34%)	13 (30%)	26 (27%)	33 (39%)
Rarely	17 (23%)	15 (23%)	11 (27%)	21 (21%)	22 (26%)
Regularly	16 (22%)	15 (23%)	12 (28%)	27 (28%)	17 (20%)
Frequently	16 (22%)	8 (13%)	6 (14%)	19 (19%)	11 (13%)
Continuously	1 (1%)	4 (6%)	1 (2%)	5 (5%)	1 (1%)
Total	74 (100%)	64 (100%)	43 (100%)	98 (100%)	84 (100%)

Notes:

1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square =5.283, df=8, p-value = 0.727. 3 cells (20%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square =6.890, df=4, p-value = 0.142. 2 cells (20%) have an expected count less than 5.

APPENDIX 4

PROXIMITY FOR INTERACTION FOR PRODUCT INNOVATION BY SECTOR AND OWNERSHIP FOR EACH INTERACTION AGENT

The results in relation to proximity for each interaction agent for product innovators by sector and ownership type are set out in Tables A4.1 to A4.6. First, Table A4.1 shows the proximity to group companies with which businesses interacted for product innovation.

Table A4.1 – Proximity[1] to Group Company[2] for Interaction for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			**Ownership[5]**	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	1 (4%)	1 (4%)	3 (10%)	3 (33%)	2 (3%)
½ to 1 hour	1 (4%)	1 (4%)	0 (0%)	1 (21%)	1 (1%)
1 to 2 hours	1 (4%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)
2 to 4 hours	0 (0%)	1 (4%)	0 (0%)	0 (0%)	1 (1%)
>4 hours	25 (89%)	23 (89%)	28 (90%)	5 (56%)	71 (93%)
Total	28 (100%)	26 (100%)	31 (100%)	9 (100%)	76 (100%)

Notes:
1. The average one-way driving time.
2. The most important group company for interaction for product innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square =6.659, df=8, p-value = 0.574. 12 cells (80%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square =17.703, df=4, p-value = 0.001. 8 cells (80%) have an expected count less than 5.

There is no evidence of a difference in the proximity of interacting group companies across sectors. However, the null hypothesis of that proximity is unrelated to ownership type is rejected (p<0.025). This indicates that foreign-owned businesses tend to interacted over greater distances, though this may be distorted by the low numbers of indigenous businesses that are members of groups of companies.

Table A4.2 shows the proximity of suppliers with which respondents interacted for product innovation.

Table A4.2 – Proximity[1] to Supplier[2] for Interaction for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			Ownership[5]	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	2 (3%)	5 (13%)	2 (6%)	7 (9%)	3 (5%)
½ to 1 hour	10 (16%)	7 (18%)	1 (3%)	14 (18%)	4 (7%)
1 to 2 hours	14 (23%)	7 (8%)	1 (3%)	8 (10%)	10 (16%)
2 to 4 hours	9 (15%)	1 (3%)	5 (14%)	6 (8%)	9 (15%)
>4 hours	27 (44%)	24 (60%)	27 (75%)	42 (55%)	36 (58%)
Total	62 (100%)	40 (100%)	36 (100%)	77 (100%)	62 (100%)

Notes:

1. The average one-way driving time.
2. The most important supplier for interaction for product innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square =23.166, df=8, p-value = 0.003. 7 cells (47%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square =6.901, df=4, p-value = 0.141. 1 cell (10%) have an expected count less than 5.

The null hypothesis of equality in the proximity of suppliers across sectors is rejected ($p<0.025$). Table A4.2 shows that businesses in the *Electronic Devices and Engineering* and, to a lesser extent, the *ICT* sector, appear to have a greater proportion of suppliers located in the middle range of distances compared to the *Chemicals and Pharmaceuticals* sector. There is no evidence of a difference in the proximity of suppliers between ownership types.

Table A4.3 shows the proximity to customers with which businesses interacted for product innovation.

Table A4.3 – Proximity[1] to Customer[2] for Interaction for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			**Ownership[5]**	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	1 (2%)	4 (8%)	3 (8%)	2 (2%)	6 (9%)
½ to 1 hour	5 (8%)	7 (13%)	3 (8%)	9 (10%)	6 (9%)
1 to 2 hours	12 (19%)	3 (6%)	4 (11%)	15 (17%)	4 (6%)
2 to 4 hours	9 (15%)	6 (11%)	6 (16%)	12 (14%)	10 (15%)
>4 hours	35 (57%)	33 (62%)	21 (57%)	49 (56%)	40 (61%)
Total	62 (100%)	53 (100%)	37 (100%)	87 (100%)	66 (100%)

Notes:

1. The average one-way driving time.
2. The most important customer for interaction for product innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square =8.589, df=8, p-value = 0.378. 5 cells (33%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square =7.316, df=4, p-value = 0.120. 2 cells (20%) have an expected count less than 5.

There is no evidence in Table A4.3 of a difference in the proximity of customers across sectors or ownership types ($p>0.025$). This is also the case for competitors, which is presented in Table A4.4.

Table A4.4 – Proximity[1] to Competitor[2] for Interaction for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			**Ownership[5]**	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	4 (11%)	2 (7%)	1 (4%)	3 (6%)	4 (12%)
½ to 1 hour	5 (14%)	5 (16%)	1 (4%)	8 (15%)	3 (9%)
1 to 2 hours	4 (11%)	3 (10%)	2 (9%)	7 (13%)	2 (6%)
2 to 4 hours	4 (11%)	1 (3%)	2 (9%)	5 (9%)	2 (6%)
>4 hours	18 (51%)	20 (65%)	17 (74%)	32 (58%)	23 (68%)
Total	35 (100%)	31 (100%)	23 (100%)	55 (100%)	34 (100%)

Notes:

1. The average one-way driving time.
2. The most important competitor for interaction for product innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square =5.399, df=8, p-value = 0.714. 12 cells (80%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square =3.173, df=4, p-value = 0.529. 6 cells (60%) have an expected count less than 5.

Table A4.5 presents the proximity of academic-based researchers with which there has been interaction for product innovation. There is no evidence of a difference in the proximity of academic-based researchers across sectors or by ownership type.

Table A4.5 – Proximity[1] to Academic-based researchers[2] for Interaction for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			**Ownership[5]**	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	7 (18%)	6 (24%)	2 (8%)	9 (17%)	6 (16%)
½ to 1 hour	11 (28%)	4 (16%)	5 (20%)	14 (27%)	6 (16%)
1 to 2 hours	8 (20%)	2 (8%)	5 (20%)	7 (14%)	8 (21%)
2 to 4 hours	5 (13%)	5 (20%)	5 (20%)	9 (17%)	6 (16%)
>4 hours	9 (23%)	8 (32%)	8 (32%)	13 (25%)	12 (32%)
Total	40 (100%)	25 (100%)	25 (100%)	52 (100%)	38 (100%)

Notes:
1. The average one-way driving time.
2. The most important academic-based researcher for interaction for product innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square =5.975, df=8, p-value = 0.727. 6 cells (40%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square =2.387, df=4, p-value = 0.665. 0 cells (0%) have an expected count less than 5.

Table A4.6 shows the proximity of innovation-supporting agencies with which there was interaction for product innovation.

Table A4.6 – Proximity[1] to Innovation-supporting agencies[2] for Interaction for Product Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			Ownership[5]	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	2 (4%)	8 (27%)	4 (15%)	12 (19%)	3 (7%)
½ to 1 hour	19 (42%)	13 (43%)	3 (12%)	26 (43%)	9 (22%)
1 to 2 hours	11 (24%)	3 (10%)	4 (15%)	6 (10%)	12 (29%)
2 to 4 hours	10 (22%)	2 (7%)	11 (42%)	12 (20%)	11 (27%)
>4 hours	3 (7%)	4 (13%)	4 (15%)	5 (8%)	6 (15%)
Total	45 (100%)	30 (100%)	26 (100%)	61 (100%)	41 (100%)

Notes:

1. The average one-way driving time.
2. The most important group company for interaction for product innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square =23.264, df=8, p-value = 0.003. 6 cells (40%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square =12.345, df=4, p-value = 0.015. 1 cell (10%) have an expected count less than 5.

The null hypotheses for equality in the proximity of innovation-supporting agencies is rejected both in relation to sectors and ownership types ($p<0.025$). This indicates that businesses in the *ICT* sector tend to be located closer to innovation-supporting agencies with which they interact for product innovation. Also, indigenous businesses tend to be closer to innovation-supporting agencies with they interact for product innovation than foreign-owned businesses.

APPENDIX 5

FREQUENCY OF INTERACTION FOR PROCESS INNOVATION BY SECTOR AND OWNERSHIP FOR EACH INTERACTION AGENT

Tables A5.1 to A5.6 present the frequency of interaction for process innovation by sector and by indigenous and foreign-owned businesses for each interaction agent. First, table A5.1 shows the frequency of interaction with group companies.

Table A5.1 – Frequency of Interaction with Group Companies for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			**Ownership[3]**	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	1 (3%)	3 (9%)	2 6%)	2 (11%)	4 (5%)
Rarely	4 (13%)	1 (3%)	3 (9%)	4 (22%)	4 (5%)
Regularly	2 (6%)	3 (9%)	4 (12%)	2 (11%)	7 (9%)
Frequently	11 (34%)	8 (24%)	9 (27%)	3 (17%)	25 (31%)
Continuously	14 (44%)	19 (56%)	15 (45%)	7 (39%)	41 (51%)
Total	32 (100%)	35 (100%)	33 (100%)	18 (100%)	81 (100%)

Notes:

1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square =4.728, df=8, p-value = 0.786. 9 cells (60%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square =7.937, df=4, p-value = 0.094. 4 cells (40%) have an expected count less than 5.

There is no evidence of a difference in the frequency of interaction with group companies across sectors or between ownership types.

Table A5.2 – Frequency of Interaction with Suppliers for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			Ownership[3]	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	10 (14%)	21 (33%)	1 (2%)	23 (24%)	9 (11%)
Rarely	11 (15%)	10 (16%)	4 (9%)	17 (18%)	9 (11%)
Regularly	17 (23%)	10 (16%)	11 (26%)	16 (17%)	22 (26%)
Frequently	18 (25%)	11 (18%)	20 (47%)	24 (25%)	25 (30%)
Continuously	17 (23%)	11 (18%)	7 (16%)	16 (17%)	19 (23%)
Total	73 (100%)	63 (100%)	43 (100%)	96 (100%)	84 (100%)

Notes:

1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square =26.336, df=8, p-value = 0.001. 0 cells (0%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square =9.052, df=4, p-value = 0.060. 0 cells (0%) has an expected count less than 5.

There is a significant difference in the frequency of interaction with suppliers across sectors ($p<0.025$); the *ICT* sector displays a lower frequency of interaction that other sectors.

Table A5.3 – Frequency of Interaction with Customers for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			**Ownership[3]**	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	16 (22%)	11 (18%)	9 (21%)	21 (22%)	15 (18%)
Rarely	7 (10%)	1 (2%)	8 (19%)	7 (7%)	9 (11%)
Regularly	19 (26%)	12 (19%)	9 (21%)	19 (20%)	21 (25%)
Frequently	16 (22%)	20 (32%)	12 (28%)	24 (25%)	25 (30%)
Continuously	15 (21%)	19 (30%)	5 (12%)	26 (27%)	13 (16%)
Total	73 (100%)	63 (100%)	43 (100%)	97 (100%)	83 (100%)

Notes:

1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square =14.837, df=8, p-value = 0.062. 1 cell (7%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square =4.643, df=4, p-value = 0.326. 0 cells (0%) have an expected count less than 5.

Table A5.4 – Frequency of Interaction with Competitors for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			**Ownership[3]**	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	41 (57%)	38 (60%)	24 (56%)	51 (53%)	53 (65%)
Rarely	20 (29%)	12 (19%)	12 (28%)	24 (25%)	20 (24%)
Regularly	6 (8%)	8 (13%)	5 (12%)	14 (14%)	5 (6%)
Frequently	4 (6%)	2 (3%)	2 (5%)	5 (5%)	3 (4%)
Continuously	1 (1%)	3 (5%)	0 (0%)	3 (3%)	1 (1%)
Total	72 (100%)	63 (100%)	43 (100%)	97 (100%)	82 (100%)

Notes:

1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square =5.427, df=8, p-value = 0.711. 7 cells (47%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square =4.943, df=4, p-value = 0.293. 4 cells (40%) have an expected count less than 5.

Table A5.5 – Frequency of Interaction with Academic-based researchers for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			**Ownership[3]**	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	37 (51%)	41 (66%)	21 (49%)	56 (58%)	44 (54%)
Rarely	20 (28%)	9 (15%)	12 (28%)	23 (24%)	18 (22%)
Regularly	11 (15%)	10 (16%)	5 (12%)	11 (11%)	15 (19%)
Frequently	2 (3%)	2 (3%)	4 (9%)	5 (5%)	3 (4%)
Continuously	2 (3%)	0 (0%)	1 (2%)	2 (2%)	1 (1%)
Total	72 (100%)	62 (100%)	43 (100%)	97 (100%)	81 (100%)

Notes:

1. The numbers in parentheses are the percentage in each sector. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square = 9.804, df=8, p-value = 0.279. 6 cells (40%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square = 2.077, df=4, p-value = 0.722. 4 cells (40%) have an expected count less than 5.

Table A5.6 – Frequency of Interaction with innovation-supporting agencies for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[1])

	Sector[2]			**Ownership[3]**	
Frequency	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
Never	31 (43%)	40 (65%)	18 (42%)	48 (50%)	41 (51%)
Rarely	18 (25%)	8 (13%)	11 (26%)	22 (23%)	16 (20%)
Regularly	16 (22%)	9 (15%)	7 (16%)	16 (17%)	16 (20%)
Frequently	7 (10%)	4 (7%)	7 (16%)	10 (10%)	8 (10%)
Continuously	0 (0%)	1 (2%)	0 (0%)	1 (1%)	0 (0%)
Total	72 (100%)	62 (100%)	43 (100%)	97 (100%)	81 (100%)

Notes:

1. Totals may not add to 100% due to rounding.
2. For sectors: Pearson's Chi-square =12.265, df=8, p-value = 0.140. 4 cells (27%) have an expected count less than 5.
3. For ownership: Pearson's Chi-square =1.292, df=4, p-value = 0.863. 2 cells (20%) have an expected count less than 5.

APPENDIX 6

PROXIMITY FOR INTERACTION FOR PROCESS INNOVATION BY SECTOR AND OWNERSHIP FOR EACH INTERACTION AGENT

Tables A6.1 to A6.6 present the average driving distances for the most important interaction agent in turn by sector and ownership type. It will be seen that a similar pattern emerges here to that seen in relation to proximity for product innovation, where other group companies, suppliers, customers and competitors with which the business interacts for process innovation do not show a tendency to be geographical close.

First, Table A6.1 shows the proximity of group companies with which there was interaction for process innovation.

Table A6.1 – Proximity[1] to Group Company[2] for Interaction for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			**Ownership[5]**	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	1 (3%)	1 (4%)	4 (13%)	3 (33%)	2 (3%)
½ to 1 hour	0 (0%)	1 (4%)	0 (0%)	1 (11%)	1 (1%)
1 to 2 hours	0 (0%)	0 (0%)	0 (28%)	0 (0%)	1 (1%)
2 to 4 hours	1 (3%)	1 (4%)	1 (1%)	0 (0%)	1 (1%)
>4 hours	27 (93%)	22 (88%)	25 (83%)	5 (56%)	71 (93%)
Total	29 (100%)	25 (100%)	30 (100%)	9 (100%)	76 (100%)

Notes:

1. The average one-way driving time.
2. The most important group company for interaction for process innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square =5.048, df=6, p-value = 0.538. 9 cells (75%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square =17.703, df=4, p-value = 0.001. 8 cells (80%) have an expected count less than 5.

The only significant difference in Table A6.1 is in relation to the proximity of group companies with which interaction occurred for process innovation between indigenous and foreign-owned businesses ($p<0.025$).

Table A6.2 shows the proximity of suppliers with which interaction occurred.

Table A6.2 – Proximity[1] to Supplier[2] for Interaction for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			Ownership[5]	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	1 (2%)	6 (17%)	1 (3%)	7 (9%)	3 (5%)
½ to 1 hour	11 (18%)	5 (14%)	0 (0%)	14 (18%)	4 (7%)
1 to 2 hours	13 (21%)	3 (8%)	3 (8%)	8 (11%)	10 (16%)
2 to 4 hours	9 (15%)	1 (3%)	7 (19%)	6 (8%)	9 (15%)
>4 hours	27 (44%)	21 (58%)	25 (69%)	42 (55%)	36 (58%)
Total	61 (100%)	36 (100%)	36 (100%)	77 (100%)	62 (100%)

Notes:

1. The average one-way driving time.
2. The most important supplier for interaction for process innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square =26.491, df=8, p-value = 0.001. 7 cells (47%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square =6.901, df=4, p-value = 0.141. 1 cell (10%) have an expected count less than 5.

It can be seen in Table A6.2 that the null hypothesis that proximity is not related to sector can be rejected (p<0.025). This indicates that suppliers tend to be spread across proximity ranges in the *Electronic Devices and Engineering* sector, while interaction tends occur over greater distances in the *Chemicals and Pharmaceuticals* sector. Table A6.3 shows the proximity of customers.

Table A6.3 – Proximity[1] to Customer[2] for Interaction for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

Distance	Sector[4]			Ownership[5]	
	Elec. Devices	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	2 (4%)	2 (5%)	4 (13%)	2 (2%)	6 (9%)
½ to 1 hour	9 (17%)	6 (14%)	0 (0%)	9 (10%)	6 (9%)
1 to 2 hours	7 (13%)	3 (7%)	6 (19%)	15 (17%)	4 (6%)
2 to 4 hours	9 (17%)	6 (14%)	4 (13%)	12 (14%)	10 (15%)
>4 hours	26 (49%)	27 (61%)	17 (55%)	49 (56%)	40 (61%)
Total	53 (100%)	44 (100%)	31 (100%)	87 (100%)	57 (100%)

Notes:

1. The average one-way driving time.
2. The most important customer for interaction for process innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square = 7.316, df=4, p-value = 0.120. 2 cells (20%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square =9.442, df=4, p-value = 0.051. 1 cells (10%) have an expected count less than 5.

Table A6.3 shows no evidence of a difference in proximity of customers across sectors. However, since the chi-square probability value is 0.051, the null hypothesis of no relationship between proximity and ownership type can be rejected with a 90% confidence level. This indicates that foreign-owned businesses tend to interact with customers over longer distances, which is not surprising since these businesses may have greater market reach.

Table A6.4 presents the proximity of competitors with which interaction for process innovation occurred.

Table A6.4 – Proximity[1] to Competitor[2] for Interaction for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			Ownership[5]	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	3 (10%)	1 (4%)	1 (5%)	3 (6%)	4 (12%)
½ to 1 hour	4 (14%)	5 (20%)	2 (10%)	8 (15%)	3 (9%)
1 to 2 hours	4 (14%)	2 (8%)	2 (10%)	7 (13%)	2 (6%)
2 to 4 hours	11 (3%)	3 (12%)	1 (5%)	5 (9%)	2 (6%)
>4 hours	17 (59%)	14 (56%)	14 (70%)	32 (58%)	23 (68%)
Total	29 (100%)	25 (100%)	20 (100%)	55 (100%)	34 (100%)

Notes:

1. The average one-way driving time.
2. The most important competitor for interaction for process innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square = 4.117, df=8, p-value = 0.846. 12 cells (80%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square = 3.173, df=4, p-value = 0.529. 6 cells (60%) have an expected count less than 5.

Table A6.4 provides is no evidence of a difference in the proximity of competitors across sectors or ownership types. This is also true for the proximity of academic-based researchers, which is shown in Table A6.5.

Table A6.5 – Proximity[1] to Academic-based researchers[2] for Interaction for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			Ownership[5]	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	8 (24%)	6 (29%)	3 (12%)	9 (17%)	6 (16%)
½ to 1 hour	9 (27%)	2 (10%)	6 (24%)	14 (27%)	6 (16%)
1 to 2 hours	6 (18%)	1 (5%)	3 (12%)	7 (14%)	8 (21%)
2 to 4 hours	3 (9%)	7 (33%)	5 (20%)	9 (17%)	5 (16%)
>4 hours	8 (24%)	5 (24%)	8 (32%)	13 (25%)	12 (32%)
Total	34 (100%)	21 (100%)	25 (100%)	52 (100%)	38 (100%)

Notes:

1. The average one-way driving time.
2. The most important academic-based researcher for interaction for process innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square = 9.883, df=8, p-value = 0.273. 7 cells (47%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square = 2.387, df=4, p-value = 0.665. 0 cells (0%) have an expected count less than 5.

The final interaction agent for which proximity is shown is innovation-supporting agencies in Table A6.6.

Table A6.6 – Proximity[1] to Innovation-supporting agencies[2] for Interaction for Process Innovation by Sector and Ownership: number of respondents (percentages in parentheses[3])

	Sector[4]			Ownership[5]	
Distance	**Elec. Devices**	**ICT**	**Chem/ Pharm**	**Indigenous**	**Foreign**
<1/2 hour	7 (16%)	9 (41%)	3 (13%)	12 (20%)	3 (7%)
½ to 1 hour	15 (35%)	5 (23%)	2 (9%)	26 (43%)	9 (22%)
1 to 2 hours	8 (19%)	2 (9%)	7 (30%)	6 (10%)	12 (29%)
2 to 4 hours	6 (14%)	3 (14%)	6 (26%)	12 (20%)	11 (27%)
>4 hours	7 (16%)	3 (14%)	5 (22%)	5 (8%)	6 (15%)
Total	43 (100%)	22 (100%)	23 (100%)	61 (100%)	41 (100%)

Notes:
1. The average one-way driving time.
2. The most important group company for interaction for process innovation identified by respondent.
3. Totals may not add to 100% due to rounding.
4. For sectors: Pearson's Chi-square = 14.693, df=8, p-value = 0.065. 7 cells (47%) have an expected count less than 5.
5. For ownership: Pearson's Chi-square = 12.345, df=4, p-value = 0.015. 1 cell (10%) have an expected count less than 5.

There is a significant difference between ownership-types in the proximity of innovation-supporting agencies with which there has been interaction for process innovation ($p<0.025$). This indicates that the innovation-supporting agencies with which indigenous businesses interact tend to be more proximate.

APPENDIX 7

LOGIT ESTIMATIONS OF THE PROBABILITY OF INTRODUCING NEW PRODUCTS

This appendix presents alternative estimates of the probability of introducing new products over the three year reference period. These estimations had lower explanatory than the estimation presented in Table 6.4, though they are presented here to show the effects on the probability of product innovation of alternative indicators of R&D and interaction.

Table A7 – Logit Estimations of the Probability of Introducing New Products

	Estimation 1		Estimation 2		Estimation 3	
	Coefficients[1]	Z-values	Coefficients[1]	Z-values	Coefficients[1]	Z-values
Business Characteristics						
Age	0.0277	1.58	0.0372	2.14[2]	0.0360	2.10[2]
	(0.0175)		(0.0174)		(0.0171)	
Size	-0.0018	-1.66[3]	-0.0021	-2.02[2]	-0.0021	-1.75[3]
	(0.0011)		(0.0011)		(0.0012)	
Turnover Growth	0.0193	0.24	0.0224	0.30	-0.0533	-0.63
	(0.0807)		(0.0753)		(0.0851)	
Foreign Ownership	-1.7945	-1.22	-1.136	-0.91	-1.4565	-1.16
	(1.4652)		(1.2464)		(1.2509)	
Group Member	2.3586	1.60	1.6660	1.31	1.9311	1.52
	-1.4699		-1.2673		-1.267	
Workforce Education	0.0045	0.44	0.0050	0.54	-0.0029	-0.28
	(0.0103)		(0.0094)		(0.0105)	
Sector						
ICT	-0.3913	-0.59	-0.3738	-0.61	-0.6277	-0.98
	(0.6628)		(0.6122)		(0.6432)	
Chemicals and Pharmaceuticals	-0.9427	-1.57	-0.8426	-1.45	-0.5711	-0.98
	(0.6007)		(0.5814)		(0.5804)	
Research and Development						
Perform R&D	1.2845	2.07[2]	1.4112	2.41[2]		
	(0.6203)		(0.5848)			
R&D Department	0.7828	1.04	0.9347	1.28	0.2873	0.36
	(0.7561)		(0.7327)		(0.7961)	
R&D Expenditure						
<5%					1.2354	2.07[2]
					(0.5981)	
6-10%					2.5113	2.34[2]
					(1.0733)	
>10%					4.1454	3.06[2]
					(1.3527)	

Table A7 continued – Logit Estimations of the Probability of Introducing New Products

	Estimation 1		Estimation 2		Estimation 3	
	Coefficients[1]	Z-values	Coefficients[1]	Z-values	Coefficients[1]	Z-values
Interaction						
Interaction Score			0.4256 (0.1665)	2.56[2]	0.4131 (0.1725)	2.39[2]
Incidence of Interaction						
Supplier	1.2942 (0.6792)	1.91[2]				
Customer	1.9448 (0.8992)	2.16[2]				
Competitor	-0.2831 (0.5386)	-0.53				
Academic	-0.3186 (0.5852)	-0.54				
Agency	0.9258 (0.6079)	1.52				
Constant	-3.0501 (1.2002)	-2.54	-1.7143 (0.9410)	-1.82	-1.3059 (0.9271)	-1.41
N	175		178		178	
Log Likelihood	-60.898		-66.575		-61.631	
Pseudo R2	0.2932		0.2455		0.3015	
LR Chi2	50.54 (0.0000)		43.32 (0.0000)		53.21 (0.0000)	

Notes:
1. The figures in parentheses are standard errors of the coefficients.
2. Significant at 5% level.
3. Significant at 10% level.

In each estimation, R&D has a significant positive effect on the probability of introducing new products. Estimation 3 uses a series of dummy variables representing the proportion of turnover spent on R&D as an indicator of R&D effort. The estimated equation indicates that, relative to the base case of no R&D expenditure, as the proportion of turnover spent on R&D increases the odds of introducing new products also increases. In each of the estimations having a dedicated R&D department does not significantly affect the likelihood of being a product innovator.

Interaction also emerges from each estimation as significantly positively associated with the likelihood of being a product innovator. In the first estimation, just as with the estimation presented in the main text in Table 6.4, interaction with suppliers and customers is significant and positive. In the first estimation above the incidence of interaction, that is a binary variable taking a value of 1 if interaction takes place, is the indicator used for each interaction agent. Estimations 2 and 3 use the Interaction Score indicator as a measure of the extent to which a business engages with interaction agents for innovation and in both cases a significant and sizeable positive relationship is found with the likelihood of product innovation.

APPENDIX 8

MULTICOLLINEARITY TESTS ON LOGIT ESTIMATION OF PROBABILITY OF INTRODUCING NEW PRODUCTS

Multicollinearity is present where several independent variables are highly correlated. Such correlation is problematic as it inflates variances, standard errors and coefficient estimates. A higher variance explained (R^2) may be due to a mis-specified model containing highly correlated and therefore superfluous independent variables. A pairwise correlation matrix is reported in Table A8.1, which is useful in identifying potential codependence between independent variables.

Table A8.1 – Pairwise Correlation of Variables in Logit Estimation of Probability of Product Innovation

	Product Innovator	**Age**	**Size**	**ICT**	**Chem and Pharm**
Product Innovator	1.000				
Age	0.038	1.000			
Size	-0.051	0.339	1.000		
ICT	-0.023	-0.255	-0.142	1.000	
Chem and Pharm	-0.069	0.217	0.145	-0.415	1.000
Foreign Ownership	-0.124	0.143	0.367	-0.123	0.190
Sales Growth	0.045	-0.299	-0.105	0.147	-0.081
R&D Dept	0.293	-0.158	0.091	0.099	-0.024
Education	0.135	-0.430	-0.135	0.497	-0.200
Group Member	-0.046	0.194	0.348	-0.048	0.234
R&D	0.368	-0.183	-0.015	0.115	-0.105
Supplier Interaction	0.238	0.081	0.043	-0.181	0.124
Customer Interaction	0.418	-0.053	-0.043	0.073	-0.071
Competitor Interaction	0.069	-0.118	-0.018	0.050	-0.094
Academic Interaction	0.063	0.013	0.142	-0.182	0.101
Agency Interaction	0.255	-0.163	0.056	-0.012	0.022

Table A8.1 continued – Pairwise Correlation of Variables in Logit Estimation of Probability of Product Innovation

	Foreign Ownership	Sales Growth	R&D Dept	Education	Group Member
Foreign Ownership	1.000				
Sales Growth	-0.078	1.000			
R&D Dept	-0.054	0.148	1.000		
Education	-0.325	0.330	0.307	1.000	
Group Member	0.804	-0.099	0.067	-0.272	1.000
R&D	-0.309	0.153	0.581	0.366	-0.208
Supplier Interaction	0.043	-0.033	0.158	-0.019	0.003
Customer Interaction	-0.100	0.084	0.336	0.298	-0.101
Competitor Interaction	-0.189	0.238	0.207	0.307	-0.194
Academic Interaction	-0.050	0.139	0.254	0.118	-0.026
Agency Interaction	-0.193	0.171	0.462	0.296	-0.068

	R&D	Supplier Interaction	Customer Interaction	Competitor Interaction	Academic Interaction
R&D	1.000				
Supplier Interaction	0.119	1.000			
Customer Interaction	0.385	0.402	1.000		
Competitor Interaction	0.162	0.148	0.241	1.000	
Academic Interaction	0.235	0.268	0.194	0.295	1.000
Agency Interaction	0.395	0.126	0.242	0.384	0.516

Source: Authors survey

Sizeable correlations are reported between group membership and foreign ownership which have a bivariate correlation of 0.804. This relationship is referred to earlier in the section. By definition foreign-owned businesses are members of a group of businesses. There is also a relatively high correlation between whether businesses performed R&D and whether businesses had a dedicated R&D department, which is an unsurprising result. Since there are few sizeable pairwise correlations, multicollinearity does not appear to be a problem for this estimation. However, further analysis is required since any variable could be a linear combination of several other variables without being highly correlated with any one of them and also there is no generally acceptable maximum level of correlation.

An alternative and superior indicator of the presence of multicollinearity is Variance Inflation Factors (VIF) and tolerances, the inverse of the VIF. VIFs are scaled versions of the multiple correlation coefficient between variable j and the rest of the independent variables. Where R_j is the multiple correlation coefficient of variable j, the VIF is calculated as

$$VIF_j = \frac{1}{1 - R_j^2}$$

Where there is no correlation between variable j and the remaining independent variables, R_j is zero. This means VIF_j is equal to 1, which is the minimum value. The inverse of the VIF is referred to as its tolerance, so the maximum tolerance is therefore 1.

Table A8.2 reports VIFs and tolerances for the logit estimation presented in Table 6.4.

Table A8.2 – Multicollinearity Diagnostics for Logit Estimation of Probability of Product Innovation		
Variable	**VIF**	**Tolerance**
Age	1.52	0.6580
Size	1.38	0.7222
Sector	1.11	0.8973
Foreign Ownership	3.45	0.2897
Sales Growth	1.21	0.8237
RD Department	1.85	0.5397
Education	1.75	0.5703
Group Member	3.26	0.3066
R&D	1.89	0.5288
Supplier Interaction	1.32	0.7589
Customer Interaction	1.52	0.6577
Competitor Interaction	1.35	0.7401
Academic Interaction	1.51	0.6605
Agency Interaction	1.86	0.5373
Mean VIF	1.79	

Source: Authors survey

As a rule of thumb, VIF greater than 10 (corresponding to a tolerance level below 0.1) suggests potential multicollinearity problems (Neter, Wasserman and Kutner, 1980). In Table A8.2 it can be seen that none of the VIFs are close to 10, providing evidence that multicollinearity is not a problem in this model and variances and standard errors are not overstated.

APPENDIX 9

TOBIT ESTIMATIONS OF PRODUCT INNOVATION INTENSITY

This appendix presents alternative estimates of product innovation intensity, as measured by the number of new products introduced per 100 employees. These estimations have lower explanatory power than the estimation presented in Table 6.5, though they are presented here to show the effects on the probability of product innovation of alternative indicators of R&D and interaction.

Table A9 – Tobit Estimations of Product Innovation Intensity

	Estimation 1		Estimation 2		Estimation 3	
	Coefficients[1]	t-values	Coefficients[1]	t-values	Coefficients[1]	t-values
Business Characteristics						
Age	-0.0034	0.33	0.0022	0.22	0.0043	0.43
	(0.0103)		0.0103		(0.0010)	
Size	-0.0016	-1.57	-0.0018	-1.75***	-0.0018	-1.83***
	(0.0010)		(0.0010)		0.0010	
Turnover Growth	0.1432	2.81*	0.1170	2.32**	0.1208	2.42**
	(0.0509)		(0.0505)		0.0499	
Foreign Ownership	0.1750	0.30	0.1924	0.34	0.3074	0.54
	(0.5815)		(0.5609)		0.5651	
Workforce Education	-0.0022	-0.32	0.0001	0.01	-0.0021	-0.31
	(0.0069)		(0.0073)		0.0068	
Sector						
ICT	-1.0280	-2.27**	-0.7281	-1.59	-0.8008	-1.79***
	(0.4521)		(0.4569)		0.4463	
Chemicals and Pharmaceuticals	-0.5200	-1.20	-0.5153	-1.18	-0.4920	-1.14
	(0.4340)		(0.4359)		0.4312	
Research and Development						
Perform R&D	0.6893	1.45			0.8820	1.91***
	(0.4765)				(0.4614)	
R&D Department	0.5711	1.33	0.6023	1.41	0.4925	1.18
	(0.4309)		(0.4285)		0.4184	
R&D Expenditure						
<5%			0.9093	1.96**		
			(0.4644)			
6-10%			0.6285	1.00		
			(0.6272)			
>10%			0.5078	0.74		
			(0.6882)			

Table A9 – Tobit Estimations of Product Innovation Intensity						
	Estimation 1		Estimation 2		Estimation 3	
	Coefficients[1]	t-values	Coefficients[1]	t-values	Coefficients[1]	t-values
Interaction						
Group Member-	0.2535 (0.5695)	0.45	0.1626 (0.5681)	0.29	0.1836 (0.5646)	0.33
Interaction Score			-0.0662 (0.1350)	-0.49	-0.0576 (0.1350)	-0.43
Incidence of Interaction						
Supplier	-0.1275 (0.1479)	-0.86				
Customer	0.3344 (0.1855)	1.80***				
Competitor	-0.1898 0.1634	-1.16				
Academic	-0.2474 (0.1719)	-1.44				
Agency	-0.0139 (0.1807)	-0.08				
Constant	-0.8492 (0.8858)	-0.96	-0.6734 (0.6924)	-0.97	-0.7821 0.7063	-1.11
N	175		178		178	
Log Likelihood	-315.299		-323.10566		-323.22368	
Pseudo R2	0.0446		0.0328		0.0325	
LR Chi2	29.46 0.0140		21.94 0.0563		21.71 0.0268	

Notes:

4. The figures in parentheses are standard errors of the coefficients.
5. * Significant at 1% level.
   ** Significant at 5% level.
   *** Significant at 10% level.

Turnover growth is the only significant indicator in all of the estimations. This was also significant in the estimation reported in the main text in Table 6.5. None of the other business characteristics indicators are significant in the reported estimation, though business size is significantly negative in two of the estimations in Table A.9. This indicates that product innovation intensity is negatively associated with the size of the business, so that the number of product innovations per 100 employees diminishes as businesses grow in terms of employment.

Just as in the estimation reported in the main text, in two of the estimations in Table A9 businesses in the *ICT* sector have significantly fewer product innovations per 100 employees than businesses in the reference sector, *Engineering and ElectronicDevices*.

Performing R&D does not have a significant effect on product innovation intensity in the estimation in Table 6.5. It emerges as a positive significant effect in Estimation 3 above and Estimation 2 indicates that spending up to 5% of turnover on R&D has a significantly positive effect on innovation intensity relative to no spending on R&D. However, the estimation does not indicate that higher levels of spending is associate dwith higher levels of innovation intensity relative to no R&D spending.

The only significant interaction indicator in the three estimations above is the incidence of customer interaction in the first estimation. The estimation reported in Table 6.5 indicated that more frequent interaction with customers was positively associated with innovation intensity. The results above indicate that those businesses that have any interaction for product innovation with customers have greater innovation intensity than those that have none.

APPENDIX 10

TOBIT ESTIMATIONS OF PRODUCT INNOVATION SUCCESS

This appendix presents alternative tobit estimations of product innovation success, as measured by the percentage of turnover attributable to new products. These estimations have lower explanatory power than the estimation presented in Table 6.6, though they are presented here to show the effects on the probability of product innovation of alternative indicators of R&D and interaction.

Table A10 – Tobit Estimations of Product Innovation Success (Product Innovators Only)

	Estimation 1		Estimation 2	
	Coefficients[1]	Z-Values[2]	Coefficients[1]	Z-Values[2]
Business Characteristics				
Age	-0.3740	-2.15**	-0.3846	-2.20**
	(0.1743)		(0.1749)	
Size	-0.0188	-1.01	-0.0187	-0.99
	(0.0187)		(0.0189)	
Turnover Growth	3.8082	4.16*	3.7569	4.10*
	(0.9146)		(0.9162)	
Foreign Ownership	-9.2126	-0.94	-10.0607	-1.01
	(9.8234)		(9.9916)	
Workforce Education	0.1623	1.32	0.1633	1.35
	(0.1225)		(0.1212)	
Sector				
ICT	9.6397	1.20	10.8359	1.34
	(8.0557)		(8.9805)	
Chemicals and Pharmaceuticals	-10.2101	-1.32	(10.4984)	-1.38
	(7.7181)		(7.6154)	
Research and Development				
Perform R&D	-0.4346	-0.05	3.4061	0.40
	(8.5723)		(8.5400)	
R&D Department	3.1311	0.43	2.2559	0.31
	(7.3571)		(7.3548)	

Table A10 continued – Tobit Estimations of Product Innovation Success (Product Innovators Only)				
	Estimation 1		Estimation 2	
	Coefficients[1]	Z-Values[2]	Coefficients[1]	Z-Values[2]
Interaction				
Group Member	18.1613	1.85***	19.9312	2.40*
	(9.8211)		(9.7654)	
Interaction Score	2.1454	2.17**		
	(0.9895)			
Frequency of Interaction				
Supplier			5.7622	2.14**
			(2.6898)	
Customer			0.0219	0.01
			(3.5178)	
Competitor			5.4455	1.94**
			(2.8088)	
Academic			-1.8851	-0.63
			(2.9964)	
Agency			1.1177	0.36
			(3.1015)	
Constant	-17.7028	-1.07	-20.6248	-1.13
	(16.5571)		(18.3102)	
N	143		141	
Log Likelihood	-589.1078		-580.0442	
Pseudo R2	0.0582		0.0631	
LR Chi2	72.84		78.12	
	(0.0000)		(0.0000)	

Notes:
1. The figures in parentheses are standard errors of the coefficients.
2. * Significant at 1% level.
   ** Significant at 5% level.
   *** Significant at 10% level.

Table A10 displays similar results to those in Table 6.6 in the main text. There is a significant negative association between the age of a business and the proportion of its turnover attributable to new products. Higher rates of turnover growth are significantly associated with greater innovation success. It may be the case that new products drive the higher rate of turnover growth.

There is no evidence in the two estimations in Table A10 that R&D activity affects the success of product innovation. Table 6.4 indicates that businesses that engage in R&D are more likely to introduce new products than those that do not. However, performing R&D does not significantly affect the extent to which the new products introduced contribute to turnover.

Interaction indicators emerge as significant and positive effects on product innovation success. This was also notable in Table 6.6. In both estimations in Table A10 being part of a group of businesses has a significant positive effect on product innovation success. In Estimation 1, higher Interaction Scores are associated with greater product innovation success. In Estimation 2 a positive association is found between innovation success and the frequency of interaction with suppliers and competitors. The positive effects of group membership and Interaction Scores are also reported in Table 6.6.

APPENDIX 11

LOGIT ESTIMATIONS OF THE PROBABILITY OF INTRODUCING PROCESS INNOVATIONS ON AT LEAST A REGULAR BASIS

This appendix presents alternative estimates of the probability of being a regular process innovator in the three-year period between 2001 and 2003. These estimations had lower explanatory than the estimation presented in Table 6.7, though they are presented here to show the effects on the probability of regular process innovation of alternative indicators of R&D and interaction.

Table A11 – Logit Estimations of the Probability of Introducing New Products

	Estimation 1		Estimation 2		Estimation 3	
	Coefficients[1]	Z-values	Coefficients[1]	Z-values	Coefficients[1]	Z-values
Business Characteristics						
Age	-0.0226	-1.90[3]	-2.0427	-1.86[3]	-0.02375	-1.91[3]
	(0.0119)		(0.0117)		(0.0124)	
Size	0.0045	1.82[3]	0.0045	1.86[3]	0.0050	1.86[3]
	(0.0025)		(0.0024)		(0.0027)	
Turnover Growth	-0.0051	-0.08	0.0105	0.17	0.0489	0.72
	(0.0637)		(0.0635)		(0.0677)	
Foreign Ownership	-0.3555	-0.5	0.1186	0.17	0.4413	0.57
	(0.7125)		(0.7151)		(0.7758)	
Group Member	0.6410	0.9	0.4083	0.59	-0.0485	-0.07
	(0.7098)		(0.6912)		(0.7456)	
Workforce Education	-0.0057	-0.7	-0.0053	-0.68	-0.0027	-0.33
	(0.0082)		(0.0079)		(0.0084)	
Sector						
	-0.1641	-0.33	-0.0493	-0.1	0.0439	0.08
	(0.5000)		(0.4946)		(0.5606)	
	-0.3167	-0.62	-0.3952	-0.74	-0.2894	-0.53
	(0.5117)		(0.5329)		(0.5510)	
Research and Development						
Perform R&D			2.0427	3.44[2]	2.4899	3.81[2]
			(0.5934)		(0.6530)	
R&D Department	-0.4231	-0.76	-0.7523	-1.31	-0.7111	-1.18
	(0.5543)		(0.5743)		(0.6008)	
R&D Expenditure						
<5%	0.9855	1.83[3]				
	(0.5398)					
6-10%	0.9311	1.24				
	(0.7510)					
>10%	1.8374	2.18[2]				
	(0.8420)					
Interaction						
Interaction Score	0.1527	2.74[2]	0.1458	2.55[2]		
	(0.0558)		(0.0571)			
Incidence of Interaction						
Supplier					1.5003	2.48[2]
					(0.6047)	
Customer					0.7688	1.50

	(0.5117)	
Competitor	0.1141	0.25
	(0.4632)	

Table A11 continued – Logit Estimations of the Probability of Introducing New Products

	Estimation 1		Estimation 2		Estimation 3	
	Coefficients[1]	Z-values	Coefficients[1]	Z-values	Coefficients[1]	Z-values
Academic					-1.0682 (0.5647)	-1.89[3]
Agency					0.4027 (0.5863)	0.69
Frequency of Interaction						
Supplier						
Customer						
Competitor						
Academic						
Agency						
Constant	-0.9664 (0.7933)	-1.22	-1.3939 -0.8281	-1.68	-1.8807 (0.8648)	-2.17
N	178		178		170	
Log Likelihood	-86.496		-82.669		-75.885	
Pseudo R2	0.1405		0.01786		0.2194	
LR Chi2	28.29 (0.0082)		35.94 (0.0002)		42.65 (0.0002)	

Notes:
1. The figures in parentheses are standard errors of the coefficients.
2. Significant at 5% level.
3. Significant at 10% level.

In each estimation, R&D has a significant positive effect on the probability of introducing new processes on at least a regular basis. In Estimation 1 spending between 1 and 5% of turnover on R&D and more than 10% increases the likelihood of regularly introducing process innovations compared to no R&D spending. Spending between 6% and 10% is also positively associated with regular process innovation though in this case the estimated coefficient is not significant. Just as with product innovation, in each of the estimations having a dedicated R&D department does not significantly affect the likelihood of being a regular process innovator.

Interaction also emerges from each estimation as significantly positively associated with the likelihood of being a product innovator. In the first and second estimations the Interaction Score is positively and significantly associated with regular process innovation. In the third estimation, only two interaction agents, suppliers and academic-based researchers, have significant estimated coefficients. Interacting with academic-based researchers though is negatively associated with regular process innovation. This was also seen in the estimation in the main text in Table 6.7 and possible explanations are presented in the main text.

APPENDIX 12

TECHNICAL NOTE ON DISCRIMINANT ANALYSIS

Discriminant analysis is used to explore independent variable mean differences between groups formed by the dependent variable. Sharma (1995) explains that discriminant analysis identifies a linear function (known as a discriminant function), b′x for k independent variables, that provides the greatest discrimination between the groups corresponding to y = 0, 1, 2….n. This discrimination is based on finding the maximum variance of b′x between groups relative to its variance within groups.

The following description of discriminant analysis is based on Maddala (1983:17). Multiple discriminant analyses are reported in the main text in Tables 7.1 to 7.3, as the dependent variable is classified into more than two categories (there are three categories in each case). For exposition purposes however the following description of discriminant analysis assumes two categories. There are n_1 observations where y = 1, representing, say, a less than two hours average one-way drive time to a business' most important customer and n_2 observations where y = 0, representing a greater than two hours average one-way drive time to a business' most important customer. The values of x, representing for example the number of new products introduced per 100 employees, in these groups are denoted by x_1 and x_2. The average number of new products per 100 employees in the first group, $\bar{x}_1$, is calculated as follows.

$$\bar{x}_1 = \frac{1}{n_1} \sum_i x_{1j}$$

The average number of new products per 100 employees in the second group, $\bar{x}_2$, is calculated as follows.

$$\bar{x}_2 = \frac{1}{n_2} \sum_i x_{2j}$$

The average for the total sample is

$$\bar{x} = \frac{1}{n_1 + n_2}(n_1 \bar{x}_1 + n_2 \bar{x}_2)$$

and

$$S = \frac{1}{n_1 + n_2 - 2}\left[\sum_i (x_{1i} - \bar{x}_1)(x_{1i} - \bar{x}_1)' + \sum_i (x_{2i} - \bar{x}_2)(x_{2i} - \bar{x}_2)'\right]$$

The variance of b′x between groups is $b'(\bar{x}_1 - \bar{x}_2)^2$. The within group variance is $b'Sb$.

The discriminant analysis chooses b to maximize

$$\phi = \frac{b'(\bar{x}_1 - \bar{x}_2)^2}{b'Sb}$$

so that

$$\hat{b} = S^{-1}(\bar{x}_1 - \bar{x}_2)$$

The discriminant functions for the two groups therefore are

$$\bar{y}_1 = \hat{b}'\bar{x}_1 = \left(\bar{x}_1 - \bar{x}_2\right)' S^{-1}\bar{x}_1$$

$$\bar{y}_2 = \hat{b}'\bar{x}_2 = \left(\bar{x}_1 - \bar{x}_2\right)' S^{-1}\bar{x}_2$$

Therefore, for any observation of the number of innovations per 100 employees, x_0, discriminant analysis calculates

$$y_0 = \hat{b}'\bar{x}_0 = \left(\bar{x}_1 - \bar{x}_2\right)' S^{-1}\bar{x}_0$$

and this observation is assigned to the first group if y_0 is closer to $\bar{y}_1$ than to $\bar{y}_2$.

Multiple discriminant analysis is used where there are more than two groups. The assignment of observations to groups in this case is also based on maximizing the difference of means between groups relative to within groups. The number of discriminant functions is equal to the lesser of g-1 where g is the number of categories in the dependent variable or p, the number of independent variables. In the analysis below the dependent variable is classified into three categories and there are six independent variables, so g=3 and p=6. This means, for the analyses reported in Tables 7.1 to 7.3 there are two discriminant functions, (g-1=2).

APPENDIX 13

DISCRIMINANT ANALYSIS OF SPATIAL DISTRIBUTION OF SUPPLIERS THAT INTERACT FOR PROCESS INNOVATION

Table A13 reports the results of a discriminant analysis using the distance to suppliers with which interaction for process innovation has taken place as the dependent variable. The discriminant functions are not found to be effective predictors of category membership [Chi-Square=8.134, df=12, p=0.775]. The analysis is presented here in the interests of completeness. Discriminant analyses for the spatial distribution of customers that interact for product and process innovation and suppliers that interact for product innovation are reported in Tables 7.1, 7.2 and 7.3 respectively.

Table A13 – Discriminant functions of the spatial distribution of suppliers that interact for process innovation

Predictor variables	Correlations of predictor variables with discriminant functions			
	1	2	F(2,123)	
Size	0.046	0.365	0.466	
Employee Education Levels	0.241	-0.227	0.250	
Perform RD	0.591	-0.380	0.272	
Foreign Ownership	0.713	0.466	1.241	
Regular Process Innovator	-0.750	0.529	0.953	
Frequency of Customer Interaction	-0.386	-0.240	0.453	
Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 2	0.935	8.134	12	0.775
2	0.982	2.237	5	0.816
	<1 hour	1 to 4 hours	>4 hours	
Size	70.11	99.38	127.13	
Employee Education Levels	44.78	36.12	37.72	
Perform RD	0.78	0.65	0.67	
Foreign Ownership	0.33	0.38	0.52	
Regular Process Innovator	0.67	0.85	0.76	
Frequency of Customer Interaction	3.56	3.74	3.52	
n	9	34	84	

Source: Author's survey

APPENDIX 14

MULTICOLLINEARITY TESTS ON LOGIT ESTIMATION OF PROBABILITY OF INTRODUCING NEW PRODUCTS INCLUDING AGGLOMERATION INDICATORS

Multicollinearity may be present where several independent variables are highly correlated. Such correlation is problematic as it inflates variances, standard errors and coefficient estimates. A higher variance explained (R^2) may be due to a mis-specified model containing highly correlated and therefore superfluous independent variables. This appendix reports multicollinearity diagnostics for the Logit Estimation of the Probability of Product Innovation including agglomeration indicators reported in table 7.10.

A pairwise correlation matrix is reported in Table A14.1, which is useful in identifying potential codependence between independent variables.

Table A14.1 – Pairwise Correlation of Variables in Logit Estimation of Probability of Product Innovation

	Innovator	Age	Size	Group	Foreign
Product Innovator	1.0000				
Age	0.0359	1.0000			
Size	-0.0698	0.3350	1.0000		
Group Member	-0.0560	0.1819	0.3506	1.0000	
Foreign Ownership	-0.1369	0.1353	0.3749	0.7998	1.0000
ICT	-0.0163	-0.2552	-0.1448	-0.0381	-0.1283
Chem and Pharm	-0.0869	0.2238	0.1549	0.2211	0.1875
R&D	0.3447	-0.1854	-0.0035	-0.1971	-0.2800
R&D Dept	0.2729	-0.1604	0.0986	0.0702	-0.0358
Supplier Interaction	0.2314	0.0709	0.0406	0.0120	0.0403
Customer Interaction	0.4113	-0.0587	-0.0459	-0.0949	-0.1029
Competitor Interaction	0.0746	-0.1191	-0.0250	-0.1979	-0.1953
Academic Interaction	0.0556	0.0072	0.1397	-0.0227	-0.0520
Agency Interaction	0.2570	-0.1703	0.0465	-0.0601	-0.1947
Labour Market Share	0.0716	-0.0670	0.0367	0.0943	0.0117
Population Density	0.1933	-0.0546	-0.0277	-0.1246	-0.1712
Distance to Airport	0.0000	0.0380	0.0729	0.0359	0.1065
Technical Employment	-0.0357	-0.1114	-0.0858	-0.0848	-0.1186
Science Education	-0.0758	-0.0132	0.0704	0.0879	0.2049
Hub/Gateway	0.0187	-0.0846	0.0580	0.0422	0.1167
Greater Dublin Area	0.0430	0.0037	-0.0726	-0.0818	-0.1829

Table A14.1 continued – Pairwise Correlation of Variables in Logit Estimation of Probability of Product Innovation

	ICT	PharmaChem	R&D	R&D Dept	Supplier
ICT	1.0000				
Chem and Pharm	-0.4161	1.0000			
R&D	0.0984	-0.1084	1.0000		
R&D Dept	0.0785	-0.0242	0.5902	1.0000	
Supplier Interaction	-0.1714	0.1031	0.1229	0.1660	1.0000
Customer Interaction	0.0783	-0.0833	0.3795	0.3341	0.4122
Competitor Interaction	0.0565	-0.1093	0.1616	0.1997	0.1524
Academic Interaction	-0.1778	0.0883	0.2386	0.2629	0.2849
Agency Interaction	-0.0033	-0.0037	0.3868	0.4571	0.1495
Labour Market Share	0.3739	0.0201	0.1324	0.0975	-0.2577
Population Density	0.2677	-0.1051	0.1402	0.0445	-0.0530
Distance to Airport	-0.2640	0.0543	-0.0570	-0.0114	0.1338
Technical Employment	0.1785	-0.1732	0.1047	0.0433	-0.1696
Science Education	-0.2511	0.1808	-0.1196	0.0333	0.1866
Hub/Gateway	-0.0993	0.0942	0.0322	0.1623	0.1258
Greater Dublin Area	0.2273	-0.1907	0.0678	-0.0545	-0.1883

	Customer	Competitor	Academic	Agency	Labour Share
Supplier Interaction					
Customer Interaction	1.0000				
Competitor Interaction	0.2452	1.0000			
Academic Interaction	0.2068	0.2972	1.0000		
Agency Interaction	0.2556	0.3846	0.5250	1.0000	
Labour Market Share	0.0478	-0.0208	-0.1814	-0.0536	1.0000
Population Density	0.1321	0.0804	-0.1177	-0.0024	0.3398
Distance to Airport	-0.0033	-0.0456	0.1379	0.0781	-0.3443
Technical Employment	-0.0058	0.0469	0.0357	0.0139	-0.0047
Science Education	-0.0520	-0.0254	0.1604	0.1001	-0.3857
Hub/Gateway	-0.0139	-0.0167	0.1782	0.2867	-0.2590
Greater Dublin Area	0.0347	0.0425	-0.2009	-0.1442	0.3366

	Pop Density	Airport	Tech Employ	Science	Hub	Dublin
Population Density	1.0000					
Distance to Airport	-0.5271	1.0000				
Technical Employment	0.2226	-0.1605	1.0000			
Science Education	-0.5554	0.5620	-0.2090	1.0000		
Hub/Gateway	-0.2151	0.1077	0.1704	0.6587	1.0000	
Greater Dublin Area	0.5207	-0.4774	0.1938	-0.9260	-0.7111	1.0000

Source: Authors survey

The only variables that exhibit large correlations are location within the Greater Dublin Area and the proportion of graduates whose degree is in a science discipline. The correlation is -0.9260, indicating a negative relationship.

Since there are few sizeable pairwise correlations, multicollinearity does not appear to be a problem for this estimation. However, further analysis is required since any variable could be a linear combination of several other variables without being highly correlated with any one of them and also there is no generally acceptable maximum level of correlation.

An alternative and superior indicator of the presence of multicollinearity is Variance Inflation Factors (VIF) and tolerances, the inverse of the VIF. VIFs are scaled versions of the multiple correlation coefficient between variable j and the rest of the independent variables. Where R_j is the multiple correlation coefficient of variable j, the VIF is calculated as

$$VIF_j = \frac{1}{1 - R_j^2}$$

Where there is no correlation between variable j and the remaining independent variables, R_j is zero. This means VIF_j is equal to 1, which is the minimum value. The inverse of the VIF is referred to as its tolerance, so the maximum tolerance is therefore 1.

Table A14.2 reports VIFs and tolerances for the logit estimation presented in Table 7.10.

Table A14.2 – Multicollinearity Diagnostics for Logit Estimation of Probability of Product Innovation		
Variable	**VIF**	**Tolerance**
Age	1.32	0.7573
Size	1.42	0.7028
Group Member	3.31	0.3018
Foreign Ownership	3.48	0.2873
Sector	1.21	0.8255
R&D	1.98	0.5058
R&D Department	1.89	0.5286
Supplier Interaction	1.50	0.6646
Customer Interaction	1.59	0.6271
Competitor Interaction	1.31	0.7642
Academic Interaction	1.66	0.6034
Agency Interaction	2.06	0.4857
Labour Market Share	1.55	0.6463
Population Density	1.84	0.5447
Distance to Airport	1.78	0.5611
Technical Employment	1.32	0.7584
Science Education	4.01	0.2496
Hub/Gatweay/Dublin Location	4.14	0.2414
Mean VIF	2.04	

Source: Authors survey

As a rule of thumb, VIF greater than 10 (corresponding to a tolerance level below 0.1) suggests potential multicollinearity problems (Neter, Wasserman and Kutner, 1980). In Table A14.2 it can be seen that none of the VIFs are close to 10, providing evidence that multicollinearity is not a problem in this model and variances and standared errors are not overstated.