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Keywords innovations, development processes, probit models, technological nature

Abstract

The aim of this study was to analyse systematic differences in the processes underlying different types of innovations. Innovations were differentiated according to their technological nature, which was measured by the radicalness and the complexity of the innovations. The innovations studied were divided into radical and incremental and into complex and simple innovations. Probit models were used to analyse how the development processes underlying radical versus incremental or complex versus simple innovations differ. The theoretical framework of the study was provided by the literature on different innovation theories.

The components of the innovation process in focus can be divided into innovation-specific and firm- or sector- specific factors. Innovation-specific factors were related to the origin of the innovation, collaboration during the development work and the role of public subsidies in the innovation process. Firm- and sector-specific factors in turn consisted of the knowledge base of the innovating firm, the size of the firm and the environment in which the innovation was developed.

The starting point for the analysis was a unique innovation database collected by the VTT Technology Studies. The database consists of basic information on some 1600 Finnish innovations commercialised in Finland mainly during the 1980s and 1990s and more detailed survey data on some 800 innovations. The analysis was based on a subgroup of this survey data, consisting of 768 innovations. Patent data and firm-level information were linked to the survey data.

The results indicate the importance of scientific and technological knowledge in developing radical or complex innovations. The importance of scientific

breakthroughs and new technologies as well as collaboration with universities and research centres was pronounced in the case of radical or complex innovations. On the other hand, innovations originating mainly from competitive pressure were more likely to be incremental. The role of public subsidies in research and development work was highlighted in the development of radical or complex innovations. The results also suggest that the environment in which innovations are developed has an effect on the type of innovative activity. Technological opportunities differ among sectors, which is reflected especially in the complexity of innovation. Favourable demand conditions in turn enhance the development of complex innovations, while at the same time allowing room for incremental innovations through more extensive product differentiation.

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Asiasanat innovations, development processes, probit models, technological nature

Tiivistelmä

Tutkimuksessa tarkasteltiin, miten teknologiselta luonteeltaan erityyppisten innovaatioiden kehittämisprosessit poikkeavat toisistaan. Innovaation teknologista luonnetta kuvattiin kahdesta eri näkökulmasta. Ensinnäkin innovaatiot jaettiin niiden uutusarvon mukaan radikaaleihin ja inkrementaalisiin innovaatioihin. Tämän lisäksi innovaatiot eroteltiin niiden kompleksisuuden mukaan monimutkaisiin ja yksinkertaisiin innovaatioihin. Probit-malleja soveltamalla tutkittiin, minkälaisia systemaattisia eroja on radikaalien innovaatioiden kehittämisprosessissa verrattuna inkrementaalisten innovaatioiden kehittämiseen sekä monimutkaisten innovaatioiden kehittämisprosessissa verrattuna yksinkertaisten innovaatioiden kehittämiseen. Tutkimuksen teoreettisena viitekehyksenä oli eri innovaatioteorioita käsittelevä kirjallisuus.

Tutkimuksessa tarkastellut kehitysprosessiin liittyvät tekijät voidaan jakaa innovaatiokohtaisiin- ja yritys- tai sektorikohtaisiin tekijöihin. Innovaatiokohtaiset tekijät liittyvät siihen, mistä innovaatioidea on alun perin lähtöisin, minkälainen yhteistyö on ollut tärkeää innovaation kehittämiselle sekä minkälainen rooli julkisella rahoituksella on ollut innovaation kehittämisessä. Yritys- ja sektorikohtaiset tekijät puolestaan liittyvät innovaation kehittäneen yrityksen osaamispohjaan, kokoon sekä yrityksen toimintaympäristöön.

Tutkimus perustui VTT Teknologian tutkimuksen keräämään innovaatioaineistoon. Innovaatioaineisto sisältää perustiedot noin 1 600 Suomessa kehitetystä innovaatiosta, jotka on kaupallistettu pääosin 1980- ja 90-luvuilla. Tätä perustietokantaa on täydennetty noin 800 innovaatiota käsittävällä kyselyaineistolla, joka sisältää yksityiskohtaista tietoa kunkin innovaation kehitysprosessista. Tutkimuksessa käytettiin 768 innovaation joukkoa tästä kyselyaineistosta, johon yhdistettiin yrityskohtaisia tietoja.

Tuloksissa nousi esille tiede- ja teknologiayhteisön merkitys, kun kehitetään radikaaleja tai monimutkaisia innovaatioita. Tieteellisten ja teknologisten läpimurtojen merkitys sekä yhteistyö yliopistojen ja korkeakoulujen kanssa korostuivat sekä radikaalien että monimutkaisten innovaatioiden kehittämisessä. Sen sijaan pääosin kilpailullisista paineista syntyneet innovaatiot olivat todennäköisemmin inkrementaalisia. Radikaalien ja monimutkaisten innovaatioiden taustalta erottuivat myös julkiset tuotekehitystuet. Toimintaympäristö, jossa innovaatio on kehitetty, näyttäisi omalta osaltaan vaikuttavan innovaation teknologiseen luonteeseen. Teknologisissa mahdollisuuksissa on sektorikohtaisia eroja, jotka heijastuvat innovaatiotoiminnan luonteeseen - erityisesti innovaatioiden kompleksisuuteen. Sektorin suotuisa taloudellinen kehitys puolestaan näyttäisi edesauttavan monimutkaisten innovaatioiden kehittämistä ja tarjoavan laajemman tuotedifferentiaation kautta tilaa inkrementaalisille innovaatioille.

Foreword

This report is based on a study carried out within the SfinnoProject undertaken in the VTT Technology Studies. The history of the SfinnoProject can be traced back to the founding of the VTT Technology Studies in 1992. At that time the idea of systematically collecting data on the development and commercialisation of Finnish innovations was introduced. Five years later, the project began to be carried out in a more systematic manner with financial support from the National Technology Agency of Finland (Tekes). The basic idea in the SfinnoProject has been to get an innovation-level understanding of the industrial renewal process in Finland during the 1980s and 1990s. This study contributes to this end by identifying systematic differences in the development processes underlying innovations of varying types.

Since 1998 three to six researchers have engaged in the SfinnoProject. This report is the sixth produced by the project. The first two reports focus on the data collection methodology and the first descriptive results of the innovation database, while the four others, including this one, are based on more focused in-depth studies. The other three topics covered concern the nature of innovation in the software sector, innovation and the success of firms, and sectoral patterns of innovation. In addition, the innovation database has been used in several other studies undertaken outside the SfinnoProject.

This report has benefited from co-operation with several persons. First of all, I would like to thank the other members of the SfinnoProject for an inspiring working environment and stimulating discussions. Especially I am indebted to the project manager, Christopher Palmberg, for his valuable comments throughout the study. I would also like to thank Professor Yrjö Vartia for his comments and Joan Löfgren for checking the language of the report. Finally, I wish to express my thanks to Tekes for their financial support. Any responsibility for errors is, of course, my own.

Tanja Tanayama

Contents

1. Introduction

1.1 Issues of interest

The past two decades have witnessed a remarkable increase in Finnish research and development (R&D) investment, which highlights the fact that technology-related issues are considered increasingly critical for economic growth and competitiveness. In 1999 Finland invested 3.1 per cent of its GDP on R&D, while the corresponding figure in 1981 was only 1.2 per cent. Along with this trend, the role of technology policy has increased as part of Finnish economic policy. The focus in Finnish technology policy has been on promoting the competitiveness of Finnish industries by technological means. That is, the creation and application of knowledge and expertise through **innovations**. The Finnish Government appointed in April 1999 stated in its programme that the future of Finland and Finns is strongly dependent on know-how, an ability to utilise know-how and create new innovations (Science and Technology Policy Council, 2000). Especially the development and application of new technologies has been considered important. Given the role of Finland as a small open economy, one goal of the technology policy has been to support the creation of new products for global markets and in that way to enhance Finnish competitiveness in the international context. The increased importance of innovation has brought about the need to understand what types of innovations are actually created and how.

There is a relatively vast literature on empirical econometric innovation studies that attempt to identify various determinants of innovative activity. The focus in these studies is on both sector- and firm-level variables that seem to determine the intensity of innovative activities within a sector or a firm. The basic underlying issue has been to identify which characteristics of a firm or a sector make some firms or sectors more innovative than others in terms of a specific quantitative proxy for innovativeness (like R&D expenditure, patents or innovation counts). Common topics have been the relationship between innovative activity and variables like firm size, market concentration, cash flow, diversification, size of the market and technological opportunity and appropriability.

Most econometric innovation studies have thus concentrated on analysing the aggregate innovative activity of firms or sectors. However, firms can be conducting several innovation projects at the same time. These innovation projects can differ greatly in terms of the characteristics related to the development process and the actual output of the process. When the analyses are done at the aggregate level it is possible to say, for example, that firms engaged in a certain type of co-operation tend to have a higher intensity of innovative activities. It cannot be said, however, to which of the firm's innovation projects this co-operation is connected and what types of innovations have been developed through this co-operation. Therefore also innovation-level understanding is needed in order to truly comprehend the functioning of innovation processes, particularly if technology policy resources are directed to facilitate a specific type of innovative activity.

In this study, the unique data at hand makes it possible to go beyond the aggregate firm- or sector-level and focus on the innovations and innovation processes underlying them. The virtue of this type of innovation level study compared to aggregate analysis is that the components of a specific innovation project can be linked to the actual output of that project. As a result, one can study the kinds of components the development of certain types of innovation requires. This is the broad topic to which this study contributes. This study takes into account the fact that innovations can be differentiated according to their technological nature. Here they are divided into radical versus incremental innovations and those with a high versus low level of complexity. The basic idea is to analyse what kinds of systematic differences can be identified in the processes generating these innovations.

Since the idea is to identify broad or average tendencies in the data rather than detail and nuance, the empirical analysis is based on quantitative statistical methods. Probit-models are used to analyse how the characteristics related to the innovation processes underlying complex versus simple and radical versus incremental innovations differ. Due to the type of data gathered for this study, the analysis is restricted to innovations developed by the Finnish business enterprise sector, mainly manufacturing. Since the data consists of actual innovations, i.e., commercialised inventions, the analysis covers only successful innovations in the sense that the development process itself did not fail. However, the commercial success of the innovations is not known.

Due to the rather unique approach employed here, the previous literature does not provide clear testable hypotheses for this purpose and therefore the empirical analysis is explorative in nature. The main issues of interest, however, rely on the theoretical discussion related to innovation processes. Namely, the origin of the innovation, co-operative links during the innovation process, the role of the public sector and the environment within which the innovation was developed. The aim was to analyse how these components of the innovation process are related to the technological nature of the final output of the process.

The structure of this thesis is the following. Some methodological aspects related mainly to the neoclassical versus the evolutionary approach are dealt with at the end of this chapter. Chapter 2 discusses technological change and the role of innovation in technological change. In addition, the term “innovation“ is clarified in terms of its use in this study. Chapter 3 reviews the main theoretical literature related to the innovation process as it is treated in the empirical analysis. Main innovation theories are presented first and the chapter concludes with theoretical discussion concerning the need for public intervention in innovative activity and the relationship between the technological environment and innovation. Chapter 4 consists of the empirical part of this study. The chapter starts with specification of the empirical framework. The measurement of innovative activities is shortly dealt with before introducing the data used in the empirical analysis. Specification of the econometric models and estimation results are presented at the end of the chapter. Chapter 5 outlines conclusions drawn from the study.

1.2 Methodological discussion

The widely acknowledged importance of technological change for economic growth and wellbeing has brought about an increasing interest in technology-related issues also within the economics discipline. In macroeconomic growth modelling this has resulted in the emergence of new or endogenous growth theory. In the basic neoclassical Solow model (Solow, 1956), technology is embedded in the exogenously determined "effectiveness of labour". Technological change has an effect on growth through exogenous shocks, which is reflected in the effectiveness of labour. In some sense, growth in this basic

Solow model has been modelled by assuming it - sustained growth is dependent on exogenous technological shocks (Romer, 1996).

The new macro growth theory launched by Romer (1986) and Lucas (1988) attempts to formulate growth as a result of endogenous rather than exogenous technological change (Lipsey, 1998). There are two main approaches employed in this newer theorising (Romer, 1996; Lipsey, 1998). The one launched by Lucas (1988) and Mankiew, Romer and Weil (1992) emphasises the accumulation of capital, while the other approach initiated by Paul Romer focuses on knowledge. Lucas as well as Mankiew, Romer and Weil consider capital as central to growth, but the traditional concept of capital is extended to include also human capital. Paul Romer instead accepts the conclusion of the basic Solow model that the effectiveness of labour is the key to sustained growth. He interprets the effectiveness of labour as knowledge and makes it endogenous by modelling its evolution over time. (An interested reader may refer to, e.g., Jones, 1998.)

The new growth theory has brought important new insights to macroeconomic growth modelling. However, once we go beyond the aggregate level and start to question how technological change actually occurs, the mainstream economic framework becomes deficient. It has currently very little to say about the contents of the black box called technology and especially the creation of new technologies. Even though some recent theoretical developments have broadened the scope of neoclassical theory, it still does not provide a detailed description of the micro-level mechanisms underlying the process of technological change, which are at the heart of this study. Therefore another framework has to be used. This framework is provided by the schumpeterian, or evolutionary, approach (see, e.g., Nelson, 1995).

A fundamental difference between the evolutionary and neoclassical approaches with respect to technological change is that while the neoclassical approach relies on the concept of equilibrium, the evolutionary approach focuses on explaining the dynamic process behind observed changes (Nelson, 1995). According to Nelson (1995), equilibrium is understood in the evolutionary approach as an “attractor“ rather than as a characteristic of where the system is. This draws on the idea that actors are regarded as searching for a best action instead of actually having found it. This is due to uncertainty related to innovative activities. Because of uncertainty it cannot be assessed *ex-ante* what would be the best action in a given situation. *Ex-post* it can be observed, which actions led to success and which did not, but still it is difficult to argue whether the materialised outcome is the best or not. Under uncertainty it is impossible to say what the optimal equilibrium state of affairs would be and whether or not it has been reached. Therefore, room for improvement can always be expected, which endogenously creates continuous technological change. Central to the explanation of technological change in the evolutionary approach is the diversity of behaviour across individual firms (Metcalfe, 1995).

According to Nelson and Winter (1974), the schumpeterian approach focuses on the role of innovating entrepreneurs, which are the real drivers of the system. Firms are seeking profits, but optimisation by careful calculation over well-defined choice sets is absent. Nelson and Winter argue that the concept of innovation, which refers to something novel, cannot be adequately characterised in terms of an induced change in choice within a given constant choice set. The competitive environment is characterised by struggle, motion and heterogeneity. It is a dynamic selection environment instead of an equilibrium one. Key factors underlying growth are innovation and selection together with augmentation of capital stocks.

The premises underlying the neoclassical and evolutionary approaches are rather different and, as can be expected, there are strong disagreements as to which one should be preferred over the other. I see the two approaches as complementary. Neither one is generally better applicable; rather it depends on which one provides a more operative framework for the problem at hand. In other words, they are designed to answer different types of questions. Methodologically neoclassical theory concentrates on formal theorising, which requires a high level of abstraction. Schumpeterian or evolutionary theory is oriented toward more realistic descriptions of real world phenomena, which makes the construction of formal theories more complicated and leads to "appreciative" theorising as Nelson and Winter call it. This is, of course, a crude distinction and in fact the two approaches have been approaching each other recently, blurring the boundary between them.

I do not want to take part in the debate over the virtues and vices of the evolutionary versus the neoclassical approach. As noted above, I think neither one can substitute for the other - both are needed. The point I want to make is that each approach has its limitations and for my purposes the key issue is, which one provides a more suitable framework for the study at hand. The goal of economics is to understand the economy so that it can be used wisely to achieve society's goals. This goal cannot be achieved if only analyses neatly fitting within the limits of a specific approach are considered appropriate. The economy is constantly changing and also the economics discipline should be adaptive to these changes. If new emerging ideas cannot be effectively studied within the existing frameworks, it should be acceptable to try something else. On the other hand, the adoption of new ways of thinking should not mean that other approaches are ultimately useless.

2. Technological change and innovation

This chapter discusses the relationship among the economy, technological change and innovation. The traditional neoclassical representation of technological change is presented in section 2.1. Section 2.2 starts with Schumpeter's trilogy of invention, innovation and diffusion. The content of each of these three phases of technological change is discussed briefly. Sections 2.3 and 2.4 focus on the concept of innovation. Section 2.3 presents the OECD's definitions of technological product and process innovations, while section 2.4 identifies different aspects of innovation.

2.1 The traditional neoclassical view

According to Stoneman (1983), technological change is the process by which economies change over time with respect to the products they produce and the processes used to produce them. In neoclassical microeconomics, technology is traditionally described by a production function. An isoquant representing the production function describes different means of production of the same output, given current technological knowledge. Any change in the relative factor prices causes movements along the isoquant, whereas a change in technology shifts the isoquant towards the origin. Technological change brings about changes in the economy's technological knowledge. The new technological knowledge makes it possible to produce greater output with the same quantity of inputs. Technological change is said to be labour (capital)- saving if it raises the marginal product of capital (labour) relative to that of labour (capital) at a given capital-labour ratio. If the effect of innovation is the same for both capital and labour, the technological change is said to be neutral (Sahal, 1981).

This traditional neoclassical representation describes so-called disembodied technological change. Disembodied technological change occurs independently of any changes in factor inputs. It is automatic, exogenous, "manna from heaven" -type change. (Embodied technological change, in turn, occurs with investment in new, improved equipment and skills. New technology is built into new equipment or trained or retained labour. While disembodied technological change is automatic, embodied is not.) Technological change is seen to have important economic consequences but it is not controlled by economic factors in any way. Technology is an exogenous variable, which comes from outside the production system and leads to adjustments in factor shares. This approach provides no conceptualisation of the technology per se.

2.2 Invention, innovation and diffusion

The traditional neoclassical view of technology supports the idea that technology and economy are two distinct phenomena and can thus be treated separately. Technology as such is seen to have important consequences for the economy, but its deeper understanding is not regarded as relevant for economic analysis. However, as will become apparent in the following chapters, technology and economy are interrelated. Not only does technology have an important effect on the economy, but also economic factors do play a critical role in the creation of new technologies. This is why the creation of new technologies can be considered as economic activity.

Schumpeter (1939) emphasised that the creation of new technologies is fundamental in explaining the dynamics of economic growth. He did not agree that technology could be considered as a separate exogenous factor in the economic system. This led him to try to conceptualise how technological change actually occurs. Schumpeter (1912, 1942) defined the creation of new technologies in three phases: invention, innovation and diffusion.

Freeman and Soete (1997, 6) have defined invention as *an idea, a sketch or model for a new or improved device, product, process or system*. An invention becomes an innovation with the first commercial transaction. An innovation is thus a commercialised invention. A patent, for example, refers more to an invention than to innovation. All inventions do not necessarily lead to innovations. Inventions are the necessary seed for technological change, but it is innovations that generate the economic benefit. This economic benefit gives profit-seeking firms the incentive to develop innovations.

Diffusion in turn describes the spreading out of an innovation within the economy. Diffusion of innovations within the economy is the fundamental link between innovation, technological change and economic growth. Metcalfe (1988, 560) has defined the diffusion of innovation as *the process by which new* *technological forms are integrated into the economy to impose changes upon its structure*. There are two basic ways in which diffusion occurs - selection and imitation (Metcalfe, 1988, Lissoni and Metcalfe, 1994). Selection refers to competition between firms developing new technological forms and firms sticking to traditional ones. When innovators strengthen their market position at the expense of non-innovators, new technological forms are diffused within the economy. Imitation refers to the replacement of old technological forms by new ones; in other words, the adoption of new technological forms by firms. Since the focus in this study is on the development of innovations rather than on the diffusion of innovations, analysis of the diffusion process is not taken up in detail.

2.3 Technological innovation

Due to the increased interest in technological change and especially innovation, words like innovation and innovative activity have become common vocabulary both in policy rhetoric and business language. However, depending on the context, the meaning of the words innovation and innovative activity can differ greatly. Sometimes they are related to almost anything that has to do with successful business activity. It is evident that for such a complicated phenomenon there is no clear-cut definition. However, due to this the lack of clear definitions, it might be useful to specify more in detail what the word innovation stands for in this study.

The concept of innovation as presented by Schumpeter and discussed above refers to technological innovation. Technological innovations can be divided into product and process innovations. According to Kamien and Schwartz (1982), product innovations involve the development of new or improved products and process innovations are technical advances in the production process. However, they note that the classification of innovations into product and process innovations depends on the perspective. An innovation can be a product innovation for its manufacturer but a process innovation for the end user of this innovation (e.g., an industrial robot).

The OECD (1997, 47) has defined technological product and process (TPP) innovations as:

"Implemented technologically new products and processes and significant technological improvements in products and processes. A TPP innovation has been implemented if it has been introduced on the market (product innovation) or used within a production process (process innovation)."

“New“ refers to the firm, not to the world. In other words, it is enough for an innovation to be new to the firm. Following the OECD's (1997, 48) definition, a technologically new product is defined as a:

"Product whose technological characteristics or intended uses differ significantly from those of previously produced products. Such innovations can involve radically new technologies, can be based on combining existing technologies in new uses, or can be derived from the use of new knowledge."

A technologically improved product, in turn, is:

"An existing product whose performance has been significantly enhanced or upgraded. A simple product may be improved (in terms of better performance or lower cost) through use of higher-performance components or materials, or a complex product which consists of a number of integrated technical sub-systems may be improved by partial changes to one of the sub-systems" (OECD 1997, 49).

And a technological process innovation is defined as the:

" Adoption of technologically new or significantly improved production methods, including methods of product delivery. These methods may involve changes in equipment, or production organisation, or a combination of these changes and may be derived from the use of new knowledge. The methods may be intended to produce or deliver technologically new or improved products, which cannot be produced or delivered using conventional production methods, or essentially to increase the production or delivery efficiency of existing products" (OECD 1997, 49).

These definitions distinguish TPP innovations from organisational innovations and other changes in products and processes. Organisational innovations refer to changed organisational structures and corporate strategic orientations as well as advanced management techniques. Examples of other changes are a new cut or colour in clothing or, in the travel industry, a package tour with new themes.

The basic OECD definition of an innovation differs in one respect from the one by Freeman and Soete presented above. In the OECD definition also non-commercialised but implemented process innovations are regarded as innovations. Firms can improve their production processes through in-house process innovations that are not necessarily brought to markets. These innovations are aimed at increasing firm competitiveness. Thus even though in-house process innovations are not commercialised, they generate economic benefit to firms. The above OECD definitions provide the definitional framework for this study. In the following, the term innovation refers always to the TPP innovation.

2.4 The nature of innovation

The above definitions distinguish among three different aspects of innovation. First of all, as already discussed, an innovation can be either *a product or a process* innovation. Secondly, an innovation can be a *technologically new or improved* product or process. Technologically new products and processes are called *radical* innovations and improved products or processes are called *incremental* innovations. According to Freeman and Perez (1988), radical innovations are usually discontinuous events and are often the result of a deliberate research and development activity in firms and/or in university and government laboratories (e.g., nylon or nuclear power). Incremental innovation can be characterised as occurring more or less continuously. Incremental innovation is often the outcome of proposals by engineers and others directly engaged in the production process or customers. The combined effect of incremental innovations is extremely important, but usually single incremental innovations do not have any dramatic effects.

A third aspect of an innovation is its novelty in geographic terms. Following the OECD's (1997) definition, a *worldwide* innovation occurs the very first time a new or improved product or process is implemented. *Firm-only* innovation, in turn, occurs when the new or improved product or process is novel for the firm but has been already implemented in other firms and industries. Firm-only innovation can be novel in the domestic context. All the above characteristics of an innovation describe the technological nature of an innovation. Moreover, the technological complexity of innovation can be used to characterise its technological nature. In addition to the technological aspect, also the economic aspect is important. Innovations differ widely in terms of the economic benefit they generate to the firm. Thus it is important also to distinguish innovations according to their economic value.

Separation of innovation into incremental and radical innovations reflects the fact that a new product or process does not remain unchanged over its life cycle - or during the diffusion process. A new product or process can go through notable changes after its first commercial transaction or implementation into the production process, which can alter significantly the economic importance of the new product or process. Therefore it is not entirely straightforward to assess the economic value of an innovation. For example, if a new product gains economic benefit only after several incremental changes, what will the economic value be of the original radical innovation that generated the new product in the first place? Both the original innovator as well as the adopters make these incremental changes to the original product or process during the diffusion process. Therefore the economic value of a new product or process can be totally different for the original innovator than to for the society as a whole.

3. Components of the innovation process

The economic benefit related to innovation leads to the central role of profit-seeking firms in generating innovations. Innovations are usually seen occurring in firms through a number of stages - i.e., as a process (Coombs et al., 1987). This chapter provides a short overview of different theories of the innovation process, starting with the so-called linear theories of science-pull and demand-push in section 3.1. Section 3.2 identifies the gaps present in the approach provided by linear innovation theories and the interactive innovation theory that emerged from these considerations is presented in section 3.3. Rothwell's extensions to interactive innovation theory are shortly dealt with in section 3.4. Section 3.5 extends the discussion of the main innovation theories by introducing the theoretical framework adopted in this study. The two remaining sections concentrate on two additional elements related to the innovation process not explicitly present in the theories reviewed, namely the role of the public sector and the effect that the technological environment and demand conditions have on innovative activity.

3.1 Linear theories of innovation[1]

Initial attempts to try to conceptualise the complex innovation process resulted in the so-called science-push (or technology-push) theory of innovation. This simple linear theory is shown in Figure 1. Following the presentation of Kline and Rosenberg (1986), the starting point of the science-push theory is research. Research leads to development, development to production and production to marketing. Each stage is seen as triggered by the output of the previous stage and there are no feedback paths between different stages. The innovation process is described as a smooth, well-behaved straightforward process.

[1] Linear refers here to the concept of time.

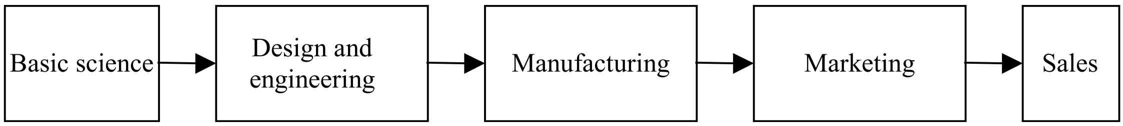

Figure 1. Science-push theory of innovation (source Rothwell, 1994).

This science-push theory of innovation is in accordance with the traditional neoclassical view of technological change. Technological change is seen as originating independently from science and can be treated as exogenous "manna from heaven".

Schmookler (1962, 1966), however, argued that economic incentives are far more important in shaping technological change than advances in science. Based on his empirical analysis of patent statistics, Schmookler claimed that even though science is an important determinant of technological change, demand conditions are the main driver of innovative activity. Schmookler argued that demand determines both the direction and the magnitude of inventive activity since 1) the ability to make innovations is responsive to profit-making opportunities; and 2) the larger the perceived market, the more innovative activity will be directed toward it (Scherer, 1982). Schmookler's ideas lead to the demand-pull theory of innovation presented in Figure 2.

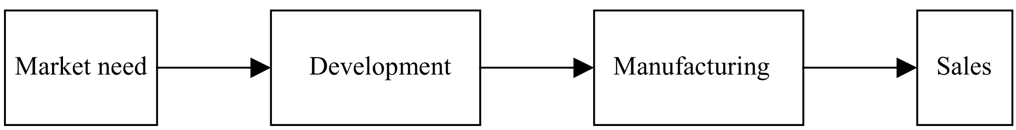

Figure 2. Demand-pull theory of innovation (source Rothwell, 1994).

Schmookler based his arguments on the idea that scientific and technological knowledge was applicable to a wide range of industrial purposes and only industries induced by demand conditions would transform this common pool of knowledge into innovations through applied research and development (Cohen, 1995). Schmookler thus assumed that technological opportunities are uniform across sectors.

3.2 Toward more sophisticated theories of innovation

The contradictory nature of the two linear innovation theories led to the reconsideration of the innovation process. This section identifies three important gaps in the framework provided by the linear theories. Section 3.2.1 deals with the rejection of the idea that either science-push or demand-pull would be the correct representation of the phenomena. In section 3.2.2 it is argued that the idea of innovation occurring as the result of a one-way straightforward linear process is a falsified simplification of the real world. Section 3.2.3 concludes by reconsidering the roles of and relationships between science and technology in knowledge production.

3.2.1 Integration of demand and science

Empirical evidence related to the demand-pull hypothesis was rather inconclusive and the 1960s and 1970s were characterised by a dichotomy between the two competing approaches - science-push and demand-pull. The empirical findings of Myers and Marquis (1969) seemed to confirm Schmookler's arguments, while Freeman, Soete and Clark as well as Scherer (1982) found much weaker relationships in re-testing Schmookler's hypotheses (Martin and Nightingale, 2000). Enhanced by Mowery's and Rosenberg's (1979) important contribution, the antithesis between demand-pull and science-push theories gave way to the integration of the two approaches. Mowery and Rosenberg (1979,143) argued that *rather than viewing either the existence of market demand or the existence of a technological opportunity as each representing a sufficient condition for innovation to occur, one should consider them as necessary, but not sufficient, for innovation to result; both must exist simultaneously*. Nowadays it is commonly agreed that the majority of innovations involve some combination of new technological possibilities and market possibilities (Freeman and Soete, 1997). Or as Kline and Rosenberg (1986, 289) put it: *A perceived market need will be filled only if the technical problems can be solved, and a perceived performance gain will be put into use only if there is a realisable market use.*

3.2.2 The importance of co-operational links

Another major drawback of the linear innovation theories is that they ignore the essential role of numerous interactions and feedback loops in the innovation process. One fundamental element of the innovation process is high uncertainty (Dosi, 1988). Uncertainty here refers to Knightean uncertainty. Knight (1921) made a distinction between measurable and immeasurable uncertainty. According to Knight, measurable uncertainty, or risk, refers to situations in which all the possible outcomes of an action are known *ex-ante* and probabilities can be assigned to them. When it is a question of immeasurable uncertainty, or true uncertainty, possible outcomes of an action are not known *ex-ante*. In economic activity, risk can be eliminated by insurance at least to some extent, while uncertainty cannot be eliminated.

Due to uncertainty, shortcomings and failures are part of the innovation process. Technological and commercial outcomes of an innovation process can seldom be known *ex ante* and the development process is unlikely to follow a one-way straightforward process. As a result, the innovation process is often described as a problem- solving activity (Dosi, 1988). New, unexpected problems emerge all along the innovation process, which need to be solved. Usually the efficient solving of these problems requires continuous co-operation among various actors in the innovation process and feedback loops in the innovation process.

Interactions and feedback loops among different actors in the innovation process are thus critical for successful problem-solving. The reason for this is twofold. First of all, co-operation provides the means to acquire informational inputs needed in problem-solving activity. However, pure information is unlikely to offer a solution to the problem by itself (Dosi, 1988). Instead, the innovator has to be able to exploit the acquired information in order to find a solution. How well the innovator can do this depends on his/her learning capabilities. Through learning, the information is transformed into knowledge about how the problem can be solved. The learning capabilities of a firm draw on its existing knowledge base (Cohen and Levinthal, 1990). In addition, the co-operational links related to the innovation process can be useful for the exploitation of knowledge. Therefore the second important aspect of co-operation is that it is likely to enhance the learning process by which innovators exploit acquired information.

Separation of information and knowledge differs from the traditional neoclassical approach. Neoclassical economics takes into account only information. Information is not necessarily freely available to everyone, but everybody who has access to the information can fully exploit it. In the evolutionary approach, innovators differ also in their capabilities to exploit information. In order to make use of acquired information, innovators have to be able to exploit the information, i.e., transform it into knowledge. The term “codified knowledge“, often used in the evolutionary literature, refers to information that can be readily transferred. Tacit knowledge in turn refers to the "know-how" that individuals have. According to Dosi (1988), tacit knowledge consists of elements of knowledge that are ill- defined, uncodified, and unpublished, which individuals possessing it cannot fully express and which differs from person to person. In this study, the terms “information“ and “knowledge“ are used. Knowledge is used as a broad concept, including both codified and tacit elements needed to solve problems

The crucial role of informational inputs and learning highlights the importance of collaboration in the innovation process. Collaboration is vital in order to obtain information, but it also enhances innovators’ learning capabilities and knowledge creation. Both external and internal collaborative partners are thus extremely important for effective problem-solving activity. “External“ refers here to collaboration with partners outside the innovating firm and “internal“ refers to collaboration within the firm. Interactions and feedback loops thus refer to well-functioning co-operation with internal and external collaborative partners. Internal collaborative partners are usually different departments within the firm, like R&D, production and marketing. External partners in turn can be universities, research centres, customers or competitors.

3.2.3 Science and technology - relations and research activities

Relations between science and technology as well as the nature of scientific versus technological research have been widely discussed in the literature. The traditional view based on the linear science push theory of innovation endorsed the idea that science, working independently of technology, was the driving force of technological change. Scientific research was equated with basic research and technological research was limited to applied research. Technology was regarded mainly as a by-product of science. In other words, science was seen to deal with the production of knowledge that is more general and fundamental to understanding principles, while technology was about applications of this knowledge, i.e., the development of products and manufacturing processes. Science and technology were sharply separated by the type of knowledge they produced. Moreover, the relation was seen to go only from science to technology.

With the rejection of the linear theory of innovation, also the relationship between science and technology and their knowledge production activities were reconsidered. Metcalfe (1995) argues that the relation between science and technology is symbiotic, instead of the sequential description provided by the linear theory. Both benefit from each other. Science is important to technology, but technology can also contribute to advances in science. Moreover, it is argued that the research activities between science and technology overlap (Hicks 1995; Dasgupta 1987). Both science and technology involve basic as well as applied research, even more so with the emergence of modern science-based industries like electronics and chemistry. According to Dasgupta and David (1987), there are strongly convergent tendencies within the research carried out under the rubric of science and technology.

As a result, there is no straightforward way of exactly separating scientific and technological research in terms of the research done or the nature of the knowledge created. For the purposes of this study, this is not necessary and scientific and technological research is regarded more as an entity. Scholars in both science and technology are engaged in scientific and technological research, the output of which is scientific and technological knowledge (STK). STK is a fundamental element in innovative activity. STK is the result of both basic and applied research and contains public as well as private knowledge. Universities, research centres and private companies produce STK, to name a few examples.

Science and technology are thus separated from each other, but the exact specification of the research activities undertaken in each of them is left outside the scope of this study. Both science and technology involve basic as well as applied research and produce both public as well as private knowledge, but in different proportions. The stand taken in this study follows Metcalfe's (1995,

465) description of the issue: *Science is not fully open, nor is technology fully closed;, rather they lie towards different ends of the spectrum*. Additional clarification is provided by Rosenberg (1974, 101), who states that *in the world of technology, economic motives are much more direct, immediate and pervasive than in the world of science*.

In this study, the focus is on innovative activity within the business enterprise sector. Therefore, without denying the connection from technology to science, the interest is more on what science provides to technology. First of all, the above discussion revealed that science contributes to the production of a general stock of STK on which innovators draw. Gibbons and Johnston (1974) list the benefits of science to technology in more detail: 1) the benefits of trained manpower; 2) cultural benefits; 3) the benefits of applied research, where the application of the research is known; and 4) the benefits resulting from the subsequent application of fundamental ideas discovered through curiosity-oriented research.

3.3 Interactive theory of innovation

Rejection of the pure technology-push or demand-pull theories resulted in innovation theories emphasising the interactive characteristic of the innovation process. Kline and Rosenberg (1986) presented the chain-linked theory of innovations, while Rothwell (1992,1994) discussed the coupling theory of innovation. These interactive theories of innovation emphasise the confluence of technological opportunities and market needs as the driving force of innovation. The innovation process is regarded as an uncertain problem-solving activity, which highlights the importance of interaction and feedback loops with both external and internal actors all along the innovation process. Figure 3 presents Kline and Rosenberg's (1986) description of the chain-linked theory of innovation.

The innovation process within the firm is described as a sequential process, but it also involves co-operation linking various functions in that process. In Kline and Rosenberg's approach, the central-chain-of-innovation that describes different phases of the innovation process goes from initial invention through design and production to marketing (see Figure 3). These different phases are connected by several feedback paths, which result from the co-operation between different phases.

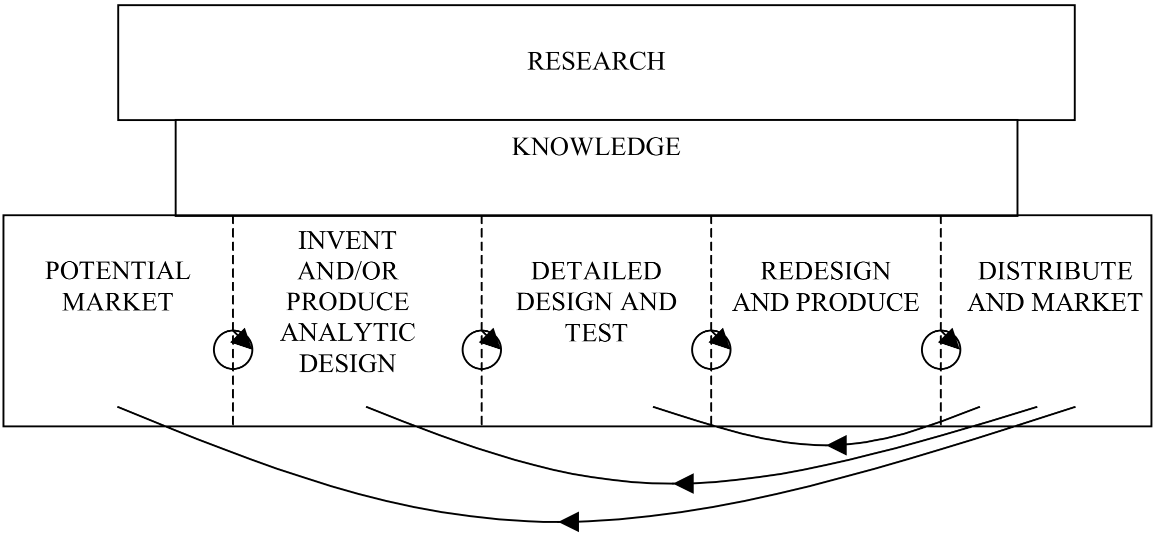

Figure 3. Chain-linked theory of innovation adapted from Kline and Rosenberg (1986, 290).

The innovation process within the firm is described as a sequential process, but it also involves co-operation linking various functions in that process. In Kline and Rosenberg's approach, the central-chain-of-innovation that describes different phases of the innovation process goes from initial invention through design and production to marketing (see Figure 3). These different phases are connected by several feedback paths, which result from the co-operation between different phases.

In addition, Kline and Rosenberg emphasise the importance of accumulated knowledge, which they call “science to innovation“. As can be seen in Figure 3, science is employed at all points along the central-chain of-innovation as needed. Kline and Rosenberg stress that the use of external sources of scientific and technological knowledge occurs in two stages. First, innovators call on the existing stock of scientific and technological knowledge; if it fails to supply the knowledge required, then research is needed.

3.4 Extending the interactive theory of innovation

Rothwell (1992, 1994) has named the technology-push, demand-pull and interactive theories of innovation the first, second and third generation innovation theories, respectively. He also goes on to describe fourth and fifth generation theories. The framework for these theories is the interactive theory of innovation. The basic building blocks are the same, but Rothwell adjusts the simplified framework to allow for a more detailed description of the nature co-operation and takes into account some new tendencies in innovative activity, like the increased importance of the speed of development.

Fourth generation theory (also called integrated theory) emphasises innovation as a more parallel rather than sequential process. Instead of considering the innovation process as a sequential process, which moves from function to function (R&D to prototype development to manufacturing), with numerous interactions and feedback loops between different functions, the process is described as a parallel development with integrated development teams (R&D, production, marketing are simultaneously engaged in innovative activity). Leading-edge customers and suppliers play a more important role in the co-operation than before and collaboration with competitors in the form of joint ventures and strategic alliances is taken into account. The fourth generation theory thus takes explicitly into account other firms as collaborative partners. It also introduces different forms of collaboration.

Fifth generation theory, also named systems integration and networking theory (SIN), is an enlarged version of fourth generation theory. It builds on the integrated parallel innovation process and adds elements like closer strategic integration between collaborating companies. The focus is thus shifting to the specific forms of collaboration. Innovation is modelled more as a networking process. Central to the process are strategic alliances and joint ventures with competitors as well as more intimate collaboration with suppliers and customers. Especially Rothwell emphasises IT-based networking. New IT technologies enable greater information-processing efficiency across the innovation network. This theory reflects the increased efficiency requirements of innovative activity. In order to achieve a fast and flexible innovation process, an increasing number of actors needs to be involved more deeply in the innovation process.

Collaborative networks allow firms to obtain and exploit relevant knowledge effectively. Also the technology has become more complex, which increases the importance of multiple informational inputs.

3.5 The theoretical framework of the analysis

The theoretical framework adopted in this study builds on the central ideas of the innovation theories presented above. The innovation process starts with the initial innovation idea. This original idea does not rely solely on either scientific and technological knowledge or demand. Instead both market needs and technological opportunities have to be in place simultaneously, as pointed out by the interactive innovation theories. However, the relative importance of science and technology or demand for the emergence of the original innovation idea can differ depending on the innovation.

Innovation can be mainly induced by a new breakthrough in technological and scientific knowledge, which makes it possible to solve some technical problems that previously have prevented the development of this type of innovation, even though the demand has already been in place. On the other hand, consumer tastes can change, so that it induces the creation of innovations that can be developed without new scientific and technological knowledge.

Changes in demand can induce innovations through two different channels: directly through consumers' changing needs and requirements or indirectly through competition. A firm can be actively screening changing market needs and requirements in the hope of conquering or finding new markets and can get innovation ideas from these changing market needs. A more passive firm, which is not actively reacting to changing market needs, can be in turn "forced" to engage in innovative activities in response to the threat of actively innovative competitors. In order to prevent declining profits, also the passive firms have to adapt to changing needs and engage in innovative activities.

In the empirical analysis, these two alternatives are termed “demand“ and “competition“, respectively. The importance of demand as a source of original ideas is measured by the importance of customer demand and observation of a market niche, whereas the importance of competition is characterised by the intensification of price competition and the threat posed by rival innovation. The importance of science and technology as a source of innovation ideas is measured by the importance of new scientific breakthroughs and new technologies.

In addition to the source of an original innovation idea, the type of development work demanded by the original idea differs. Four types of development activity related to innovation ideas are considered in the empirical analysis: the productisation of a particular core technology; the development or combination of different types of components of modules; development of production methods; and the productisation of service concepts.

Key characteristics of the innovation process within the firm are described in Figure 4. Within the firm the innovation process is divided into different phases of research, design and development, prototype production, manufacturing and marketing and sales. Different departments of the firm are co-operatively engaged in the innovation process all along, but to varying extent, depending on the phase. In the beginning of the process, the role of the R&D department is highlighted, while towards the end, the roles of first the production and then the sales department increase.

Due to uncertainty inherent in innovative activity, shortcomings and failures are part of the innovation process. Therefore even though the process is divided into different phases, progress is not necessarily one-way or straightforward. Instead, there can be several steps backward in the process, for example from manufacturing back to research, design and development.

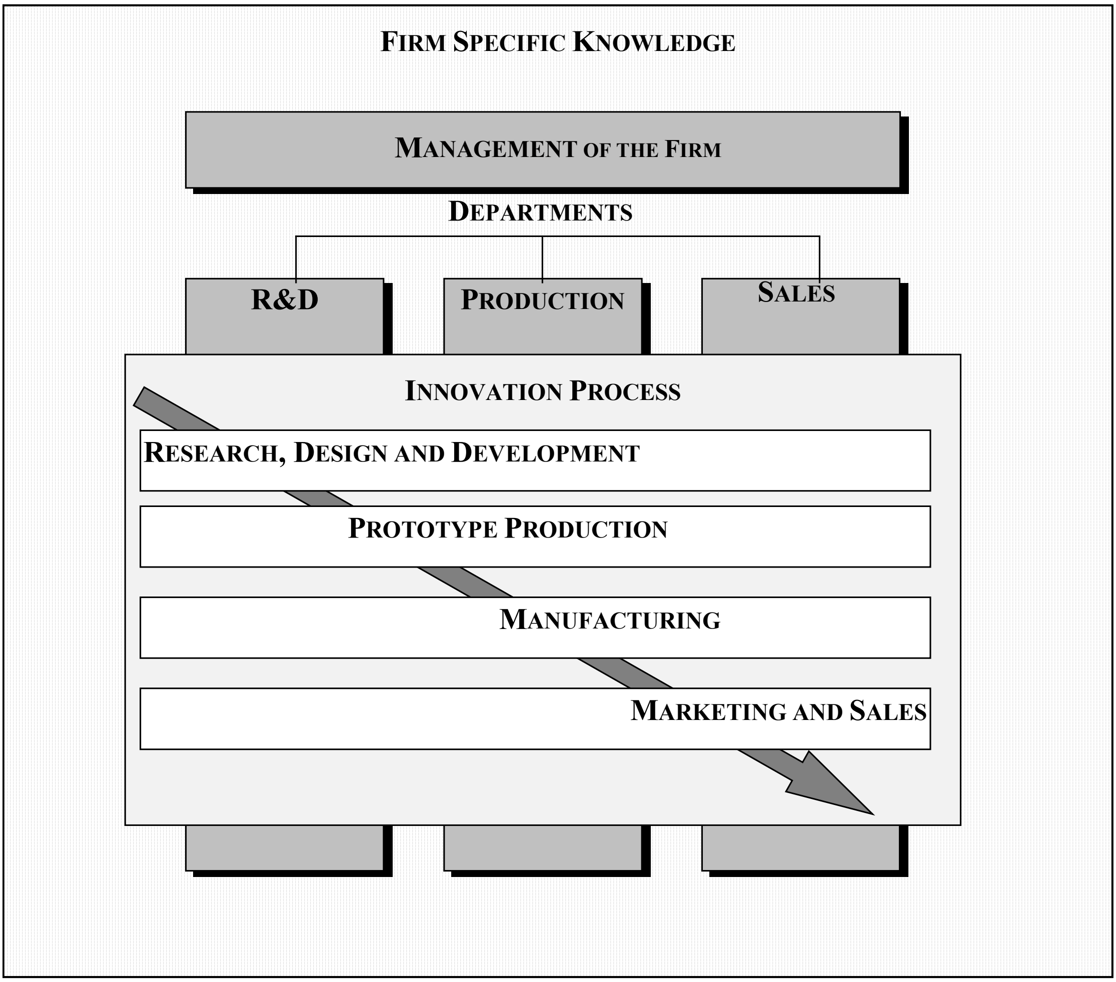

Figure 4. Innovation process within the firm.

As described in section 3.2.2, the innovation process can be viewed as a problem-solving activity. New, unexpected problems emerge all along the innovation process that need to be solved. Relevant knowledge is critical in this problem-solving activity. A firm's accumulated knowledge, i.e., firm-specific knowledge, is the first source to which firms resort when problems emerge. Cohen and Levinthal (1990) have related this firm-specific knowledge to basic skills, shared language and knowledge of the most recent scientific and technological developments. The management of the firm as well as different departments of the firm contribute to the firm-specific knowledge. Therefore, in order to fully exploit the capabilities within the firm, efficient internal co-operation is required. However, often external sources of knowledge are also needed. Figure 5 presents the knowledge requirements of the innovation process.

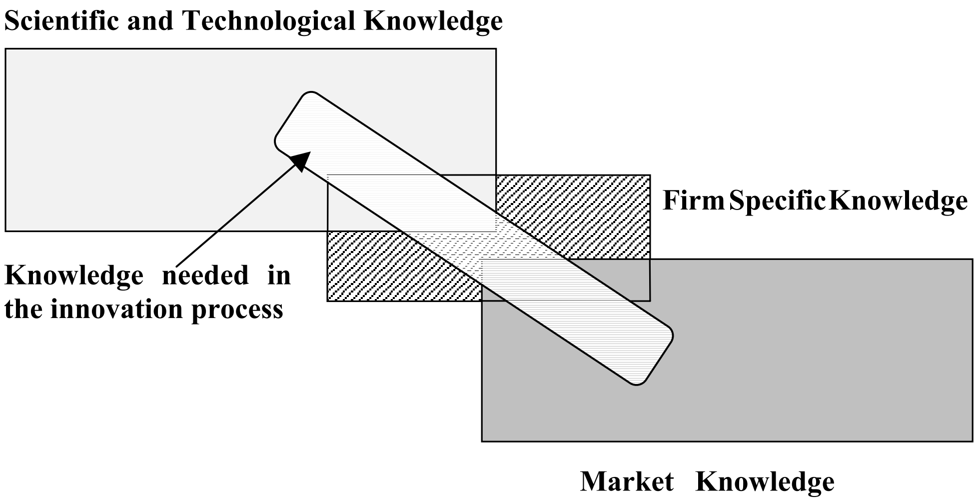

Figure 5. Knowledge requirements of the innovation process.

In Figure 5 knowledge is divided into scientific and technological knowledge (STK), firm specific knowledge and market knowledge. STK consists of the existing stock of scientific and technological knowledge and research. Market knowledge includes knowledge about demand conditions, consumer needs, market possibilities, etc. Relevant external collaborative partners within the categories of STK and market knowledge are universities, research centres, customers and other firms. STK and market knowledge represents knowledge available outside the firm. Firm-specific knowledge consists of both STK and market knowledge. Part of it is available also outside the firm, but some is specific to the firm. As shown in the figure, firm-specific knowledge is often not enough in order to achieve a successful end to the innovation process. In seeking solutions to emerging problems, a firm is most likely to acquire outside knowledge inputs by engaging in co-operation with external actors all along the innovation process.

Advantages the innovator can get from external co-operation depend partly on its firm-specific accumulated knowledge base. Firm-specific knowledge is a fundamental determinant of the firm's learning capabilities and is therefore an important determinant of how effectively the innovator can exploit the acquired knowledge and create new knowledge through research and development. From an empirical point of view, the concept of a knowledge base is, however, very abstract and obscure. In this study, the operationalisation of the knowledge base has been attempted through measuring the diversification of the innovator's knowledge base. This was constructed using data on granted patents.

In the empirical analysis, the data permits taking into account only external linkages. These external linkages include collaboration with customers, other firms and universities and research centres. Collaboration with other firms can be further divided into horizontal and vertical collaboration. Horizontal refers to collaboration with competitors and vertical to collaboration with suppliers. Universities and research centres are mainly a source of technological and scientific knowledge, consumers provide information about market needs and requirements, and other firms can serve both purposes. There can be several collaborative partners linked to one innovation process and the relative importance of these partners can differ.

3.6 Why is the public sector needed in innovative activity?

The discussion in section 3.2.3 revealed that scientific and technological knowledge comprise fundamental elements in the creation of new technologies. Knowledge, however, compared to more conventional resources like natural resources, capital and labour, has some peculiar characteristics, which call for government intervention. This section presents two arguments that call for government intervention. Section 3.6.1 discusses the traditional market failure argument and section 3.6.2 adds an evolutionary flavour to the discussion.

3.6.1 The supply of knowledge

A key argument in favour of government intervention is the familiar market failure argument (Arrow 1962, Nelson 1959). Arrow (1962) distinguishes three special characteristics related to knowledge[2] that lead to market failure: indivisibility, inappropriability and uncertainty.

The indivisibility of knowledge gives it some characteristics of a public good. Indivisibility means that if a piece of knowledge is transferred to another user, the amount of knowledge is not reduced. For socially desirable allocation, knowledge should thus be freely available (assuming that transmission costs are negligible). This, however, would give no incentive to produce knowledge and there would be an underproduction of it. Even if the goal of the socially desirable allocation of knowledge is abandoned, the inappropriability of knowledge makes the reliance on market mechanisms alone impossible. Appropriating the returns of knowledge production is difficult, since any purchaser can reproduce the knowledge at little or no cost. Only the production of knowledge for the producer's own use would be efficient. Uncertainty related to innovative activity complicates matters further. The inability of firms to buy protection against uncertainty results in underinvestment in innovation. (Arrow, 1962).

Market failure caused by indivisibility, inappropriability and uncertainty thus requires government action. Dasgupta and Stoneman (1987) present three possible routes for government intervention. First of all, the government can grant producers of new knowledge intellectual property rights to their discoveries and allow them to charge fees for their use by others. Secondly, the government can engage directly in the production of knowledge, allow the free use of it, and finance expenditures on knowledge production through taxes. Thirdly, the government can encourage the private production of knowledge by providing subsidies financed by taxes. Nowadays all of these forms of government intervention are common policy measures in science and technology policy. The patent system provides the means to grant producers of knowledge certain types of property rights. The government is engaged in the production of knowledge through universities and government-financed research centres. And

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[2] The market failure argument relies on the traditional neoclassical framework. As mentioned in section 3.2.2, the neoclassical framework takes into account only information. Therefore the concept of knowledge used in relation to the market failure argument refers more to codified knowledge, i.e., information.

R&D subsidies are used to encourage the private production of knowledge, which would not otherwise be undertaken due to high levels of uncertainty.

The above reveals the somewhat contradictory nature of scientific and technological knowledge - it should be both a public and a private good (Nelson, 1992). Due to the economic benefits related to innovation, firms have a central role in generating technological change in the capitalist system. Appropriation of the benefits related to innovation is, however, unsatisfactory in the absence of government interaction, because of the special nature of knowledge. If the appropriation were left to markets alone, there would be underproduction of innovation. Through its patent system, a government can increase the private good properties of scientific and technological knowledge and stimulate innovative activities within firms. However, from society's point of view, scientific and technological knowledge should be a freely available public good, so that the benefits of new knowledge could spread as widely as possible. Spreading scientific and technological knowledge enhances the diffusion of innovations within the economy, which is the fundamental link between innovation, technological change and economic growth. Nelson (1992) also argues that the going public of knowledge contributes to the advance of technology, as more parties are involved in improving it.

3.6.2 The exploitation of knowledge

The traditional market failure argument for government intervention has been criticised for overemphasising the supply of knowledge (Mowery, 1994). All of the above government interventions resulting from resulting from market failure are intended to increase the supply of knowledge. It has been argued that also the high costs of transferring and utilising knowledge should be taken into account (Rosenberg 1976, 1982 in Nelson 1992). Partly this relates back to the discussion on the links between information and knowledge in section 3.2.2. Supply side policies that arise from the market failure argument consider knowledge more like information, which can be transferred and applied at no cost. However, as discussed in section 3.2.2, it is not enough to have access to information. What is of crucial importance is the ability to exploit the information. Policy measures resulting from market failure are thus seen as insufficient.

One consequence of the perception that knowledge is not automatically transferred is that also the adoption of new technologies is seen to require government intervention (Mowery,1994). Government-led technology programmes, which aim at the diffusion of technological knowledge through collaboration and networking, are an example of this type of government intervention. Public procurement of advanced technology instead increases market demand and can in that way accelerate the development and application of new technologies. Establishing standards can also enhance the adoption of new technologies.

The broader issue underlying the need to be able to exploit available knowledge is learning. As discussed in section 3.2.2, learning is the way by which firms exploit information and create new knowledge. This leads to the concept of a National System of Innovation launched by Lundvall (1988) and Freeman (1987), which has gained importance in the science and technology policy discussion.

The National System of Innovation approach attempts to anchor innovative activities to the broader institutional and national context. Lundvall (1992) based his elaboration of the concept on the fundamental role of learning in innovative activities. Learning is of central importance both for the creation of innovations and their diffusion. Lundvall sees learning as an interactive and socially embedded process, which cannot be understood without taking into consideration its institutional and cultural context. Based on these premises, Lundvall (1992, 2) defines a system of innovation as *constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge*. A national system in turn *encompasses elements and relationships either located within or rooted inside the borders of a nation state*.

The national system of innovation approach broadens the scope of public policy in relation to innovation. According to Martin and Nightingale (2000), the National System of Innovation approach suggests that government policy can affect many of the institutions that influence the success of innovation. Metcalfe (1995, 462) defines a national system of innovation as a *set of distinct institutions which jointly and individually contribute to the development and* *diffusion of new technologies and which provide the framework within which governments form and implement policies to influence the innovation process*.

To sum up the discussion, the market failure argument provided the first basis for government intervention in innovative activities. The market failure argument draws on the uncertainty related to innovative activities and the indivisibility and inappropriability of knowledge. Based on the market failure argument, the government should intervene in a twofold manner. On the one hand, it should enhance the appropriability of innovations and on the other hand, it should enhance the creation of the publicly available stock of knowledge. These policies, however, do not take into account the fact that transmission and utilisation of the existing knowledge is often costly. Therefore also the adoption of innovations requires government interventions. Finally, the shift away from the supply of knowledge to the exploitation of knowledge has highlighted the fundamental role of learning in innovative activities. This has broadened the policy discussion to the institutional setting of innovative activities. It is argued that effective operation of the innovation system depends on the effective coupling of firms and other knowledge-based institutions to jointly enhance the processes of learning and creativity (Metcalfe, 1995).

In the empirical analysis carried out in this study, the role of the public sector is analysed by focusing on government-induced regulation and public funding of innovative activities. Government-induced regulations can be a source of original innovation ideas. Regulation provides the means for the government to enhance the diffusion of innovations. The government can induce firms to innovative activities through regulations, legislation and standards. Also environmental factors as a source of innovation ideas are regarded in this study as part of regulation. Even though firms may be reacting to environmental factors before any regulations are put in place, the expectation concerning future regulations is often an important driver of this activity. Therefore the factor called "regulation" measures the importance of environmental factors as well as official regulations, legislation and standards as sources of original innovation ideas. There was a relatively high correlation between environmental factors, on the one hand, and regulations, legislation and standards on the other, supporting the combination of these factors into one (Spearman correlation coefficient 0.51).

Public funding of innovative activities is divided into two components in the empirical analysis: public funding related to technology programmes and other sources of public funding. Subsidies create incentives for firms to engage in innovative activities that otherwise would be regarded as unprofitable due to high uncertainty or weak appropriability of the output. Technology programmes, in turn, are especially aimed at enhancing the diffusion of technological and scientific knowledge through collaboration. Therefore technology programmes do not only offer money but also other types of support.

3.7 The technological environment and demand conditions

The discussion of the importance of market demand and technological opportunity for innovation to occur in section 3.2.1 highlights the point that the environment in which the firm operates has an important effect on innovative activities. Perceived sectoral differences in firms' innovative activities indicate that this environment is not the same for all firms. Firms are heterogeneous in characteristics, behaviour and performance within sectors but at the same time there are sector-specific regularities, which shape the innovative activities within the sector. In other words, the innovative activities within a sector are to some extent restricted by its environment. Based on this observation, there has been a lot of interest in studying the main components of the environment that have an effect on innovative activity and how such components differ across sectors.

The idea of sectoral patterns of innovative activity originates from Schumpeter (1912, 1942). First he identified the sectoral pattern of creative destruction in which new small firms are the main generators of technological change. This pattern was later named the Schumpeter Mark I. Characteristic of this pattern is the technological ease of entry. New small firms generate innovations, which challenge the incumbent firms and reshape the existing technological structures. Later Schumpeter highlighted the importance of institutionalised, professional R&D laboratories in creating new innovations. This pattern is called Schumpeter Mark II. It emphasises the idea of creative accumulation and focuses on the role played by large firms. In these patterns, firm size and market structure are the underlying factors explaining sectoral differences (Klevorick et al., 1995). Schmookler instead argued that sectoral differences are due to different demand conditions (Cohen, 1995), more specifically the market size and growth in demand (Klevorick et al., 1995).

During recent decades the scholarly discussion of innovation has focused on the technological environment and concepts like technological opportunity and appropriability have been emphasised. It is still an open question, which are the key characteristics determining this technological environment. Nelson and Winter (1977) were among the first to discuss the issue. They started with an abstract definition of a *frontier of achievable capabilities, defined in the relevant economic dimensions, limited by physical, biological and other constraints, given a broadly defined way of doing things* (1977, 57). Dosi (1988) in turn discussed extensively the sources of inter-sectoral patterns of innovation and found factors like technological opportunities, appropriability conditions, knowledge bases and search procedures behind sectoral differences. Malerba and Orsenigo (1990 and 1993) continued further and proposed that the technological environment is a particular combination of technological opportunity and appropriability conditions, degree of cumulativeness of technological knowledge and characteristics of the relevant knowledge base.

Malerba and Orsenigo (1997) have described the contents of technological opportunity and appropriability conditions, degree of cumulativeness of technological knowledge and characteristics of the relevant knowledge base in the following way. Technological opportunity conditions refer to the easiness of innovating for any given amount of resources invested in innovative activities. Opportunity conditions can differ in level, pervasiveness, source and variety. Appropriability conditions, in turn, characterise the possibilities of protecting the outputs of innovative activities. There can be different levels and different means of appropriation. Cumulativeness conditions describe to what extent today's innovations are dependent on firm's previous innovative activities. Cumulativeness can be due to learning processes, organisational sources or 'success-breeds-success' processes. The knowledge base defines the properties of the knowledge upon which firms' innovative activities are based. It has two dimensions, the nature of knowledge and the means of knowledge transmission and communication.

The empirical evidence related to the key variables explaining sectoral patterns is rather inconclusive. The only quite commonly agreed conclusion is related to size and market structure. Both are seen as having little influence on innovative activity as such. Instead, they rather reflect the influence of some underlying variables like appropriability and opportunity on innovative activity. Demand, appropriability and opportunity are regarded as good candidates to explain the inter-sectoral differences, but their inclusion in econometric empirical studies is problematic. They are extremely difficult to measure and concepts like technological opportunity or appropriability are difficult to make precise and empirically operational. (For a detailed discussion on the empirical literature see Cohen, 1995.)

The data at hand does not provide appropriate measures to characterise the technological environment in detail. Therefore in the empirical analysis it is assumed that different product groups are characterised by different technological environments and product group dummy variables are used in order to control for the possible effect the technological environment might have on the type of innovation developed within these groups. Capturing the effect of demand conditions was attempted through measuring the average growth rate of the relevant product group over the five years prior to the commercialisation of the innovation.

In addition, the size of the firm, as measured by the number of employees at the time of the commercialisation of the innovation, is included in the empirical analysis. As mentioned above, previous studies indicate that the firm size itself is unlikely to have an effect on innovative activities, rather it often reflects the effect of underlying industry and firm-level factors like technological opportunity and appropriability. However, as the data at hand does not provide accurate means to control for the effect these underlying factors may have on innovative activity, firm size is included in the analysis instead. However, the special nature of this variable has to be borne in mind when interpreting the results.

4. Empirical analysis of the innovation process

The discussion in the previous chapter reveals that there is quite a good understanding of the main components of the innovation process. It is widely accepted that for the majority of innovations to occur, both market need and technological opportunity must be in place. Comprehension of the innovation process as a problem-solving activity based on knowledge creation highlights the role of co-operation and the knowledge base. Uncertainty as a key characteristic of the innovation process, together with the special characteristics of knowledge as a good, leads to the need for government intervention. The technological environment and demand conditions within which firms operate differ across sectors, causing sectoral patterns of innovation.

For a complete understanding of innovation it is not, however, sufficient to identify the fundamental determinants of innovation. It is also important to understand how the components of the innovation process are related to the actual output of the process. For this we need to differentiate various types of innovation and identify the processes underlying these different types of innovations. It is likely that innovation processes resulting in different types of innovations contain different mixture of the components. The objective of this study is to shed some light on these issues.

This chapter constitutes the empirical part of this study. Section 4.1 specifies the empirical setup of the analysis. Section 4.2 presents the data and discusses issues related to innovation measurement. Section 4.3 introduces the econometric models to be estimated. The chapter ends with section 4.4, which covers the estimation results .

4.1 The empirical setup

The basic idea behind the empirical setup is to differentiate innovations according to their technological nature and analyse what kinds of systematic differences can be identified in the processes generating these innovations. The broad research question is thus the following:

How do the characteristics related to the development process of innovations differ among innovations of various technological types?

The technological nature of an innovation is characterised by two different aspects. Innovations are divided into radical and incremental innovations as well as into high and low-complexity innovations. In the following, high complexity innovations are called “complex innovations“ and low complexity innovations are called “simple innovations“.

Adding the different types of innovation defined above into the basic research question, it can be specified further as follows:

How do the characteristics related to the development process of radical versus incremental and complex versus simple innovations differ?

The setup of the empirical study can be characterised as follows. The starting point is that firms develop innovations. They get innovation ideas, which they decide to put into practise. In order to be able to get through the development process, they need the resources and knowledge necessary to solve emerging technical problems. The outcome of this process is an innovation which is either radical or incremental and either complex or simple. Due to the great uncertainty related to innovative activities, it cannot be determined *ex-ante* what the outcome of the innovation process will be. However, it is assumed that an innovation process with certain characteristics is likelier to result in an innovation of a specific technological nature.

The innovation process can be considered to start with the innovation idea that the innovator decides to put into practise. The original idea does not determine the technological nature of the innovation, but it is assumed that the innovation is likely to be of a certain type depending on the type of the original idea. Original ideas are assumed to differ in two respects.

First of all, the relative importance of the various factors that have given rise to the original idea differs. This may be partly due to the innovation strategy the innovator has chosen. If the innovator decides to be an active forerunner in the fields related to the idea, the innovator is likely to follow closely --and even be part of-- technological and scientific advances. On the other hand, for a firm relying on imitation, competition might be a relatively more important factor. Secondly, the type of development work required by the idea differs, which is also assumed to affect the likelihood that the resulting innovation is of a certain type.

Once the innovator has decided to proceed with the original idea, he/she has to find funding for the development process. In this study, only public funding is considered as a separate source of funding. The funding of the process can therefore be a combination of public funding and other sources of funding or completely from other sources of funding. Public funding is expected to be directed towards certain types of innovation projects according to the emphasis of the technology policy. It cannot be denied that other sources of funding are also likely to have an effect on the type of innovation developed. However, more detailed analysis of the effects of different sources of funding on innovation cannot be analysed within this study. Another issue the firm has to decide is in what kind of co-operation to engage. It could be expected that depending on the type of innovation process in question, different external collaborative partners are needed.

The above components specify the central characteristics of the innovation process, which are of interest in this study. However, since it is question of a non-experimental setting, there are likely to be several underlying factors that have an effect on the technological nature of innovation, which are correlated with the characteristics of the innovation process, causing spurious correlations. In order to reduce the problem of spurious correlations, the effect of these underlying factors should be taken into account in the analysis.

As discussed earlier, demand conditions and the technological environment as well as the characteristics of the firm are likely to have an effect on the type of innovative activities the firm is engaged in. Therefore these are the underlying characteristics the effect of which should somehow be controlled for in the empirical analysis. However, it is unrealistic to assume that all the effects of the underlying characteristics could be taken into account. This has to be kept in mind when interpreting the results. Especially any interpretations of causality should be avoided (see, e.g., Lilja and Vartia, 1980). The explorative nature of the analyses further highlights the fact that instead of trying to find causalities, the focus is on identifying some central features that differentiate innovation processes underlying innovations of varying technological nature.

4.2 Data

4.2.1 How to measure the output of innovative activities?

A fundamental problem in the empirical studies of innovation is the lack of satisfactory measures for innovative output. There exists no measure of innovation that permits readily interpretable cross-sectoral comparisons and moreover the value of an innovation is difficult to assess (Cohen and Levin, 1989). Different types of science and technology indicators have been used as a proxy for innovative activity. The focus here is on the firm-level innovation indicators used in quantitative empirical studies of the business enterprise sector. The most widely used indicators are R&D expenditure, R&D personnel and patent statistics. For all these three indicators, data are collected and analysed according to a standardised methodology (Sirilli, 1998). R&D measures are so-called "input indicators" of technological activity, since they measure resources devoted to innovative activities. Patent statistics in turn are more a measure of intermediate output. There are, however, several problems related to these major indicators.

First of all, the R&D-related indicators suffer from the inherent problem of using input measures to proxy the output. Depending on the firm and the sector, inputs of innovative activity are transformed differently into output. Moreover, R&D expenditure is only one kind of input and factors like learning in connection with routine activities may be even more important (Rosenberg, 1982). Despite standardised methodology for collecting data, the R&D-related indicators are also subject to considerable error in reporting due to vague accounting principles. R&D indicators also exclude innovative activities that are performed outside formal R&D laboratories. This is especially the case in many small firms.

An additional problem is caused by the fact that R&D is often classified by the firm's principle activity. However, the output of innovative activities can include innovations outside the firm's principle activity. For example, in the innovation database collected by the VTT Technology Studies, over half of the innovations are outside the firm's principle activity.

Patents instead are more an intermediate measure of innovative output. Not all innovations are patented and not all patents lead to innovations. Moreover, patenting policies can vary considerably across different sectors. (For a more detailed discussion of the problems related to different indicators, see Patel and Pavitt 1995, Cohen and Levin 1989 and Geroski 1994.)

In response to the problems related to the above indicators, direct measures of innovative output have been developed - the innovation surveys and innovation counts. Innovation surveys can be divided into two groups depending on the survey methodology. The Community Innovation Survey (CIS), which is the harmonised innovation survey conducted by Eurostat, represents the subject approach. CIS follows the guidelines provided in the OECD's Oslo Manual (OECD, 1997). Other examples of the subject approach are the PACE survey conducted by the Dutch research institute MERIT, Aalborg University and the French statistical office INSEE (Arundel et al., 1995). In the subject approach, the data is collected on the innovator. A questionnaire is sent to firms belonging to a chosen sample in order to collect information on the firm's innovative activities; for more details, see OECD (1997).

The other type of innovation survey is based on the object approach. Whereas in the subject approach the data is collected on the innovator, in the object approach the data is collected on the individual innovation. The innovations can be identified, for example, through literature reviews (Acs and Audretsch, 1990; Kleinknecht et al., 1993) or expert interviews (Townsend et al., 1981). The term "innovation counts" usually refers to this type of data collection. Additional information on the innovations and their development can be collected through a survey addressed to the innovators. (For more details on the object approach, see Palmberg et al., 1999.) The virtue of innovation counts and innovation surveys is that they attempt to measure directly the output of innovative activity and as such are probably the best proxy for innovative output. However, they have their own faults as well, a fact that has to be taken into account in the analysis.

The starting point for the empirical analysis in this study is the innovation database collected by the VTT Technology Studies (hereafter the Sfinno database) (Palmberg et al., 1999). The Sfinno database contains basic data on some 1600 Finnish innovations commercialised in Finland during the 1980s and 1990s and more detailed survey data on some 800 innovations (Palmberg et al., 2000). The innovation data is collected using a unique application of the object approach. The data collection methodology is presented in the next section.

4.2.2 Sfinno methodology

The methodology used to collect the Sfinno data is presented in Figure 6. As already mentioned, it is an application of the object approach. The main strength of the object approach compared to the subject approach is that it provides data on specific innovations instead of on the overall innovative activities of a firm. Moreover, it can cover also the very small firms that are often excluded from surveys like the CIS. The methodology, definitions and criteria used in the data collection are reported in Palmberg et al. (1999) in detail. Only the main issues will be covered here. The innovations are identified through three different channels: literature reviews, expert interviews and annual reports. Since the chosen methodology for data collection follows the object approach, pure process innovations developed for the firm's own use are excluded.

The underlying definition of a product innovation has been an invention that has been commercialised on the market by a business firm or equivalent. The minimum requirement for commercialisation is that there has been at least one major market transaction. In the data collection, the novelty of an innovation was determined following the guidelines provided by the OECD's Oslo Manual (1997). Since the focus was on Finnish innovations, only innovations commercialised by a firm registered as domestic in the Finnish registers have been included in the database. Patent data on all the Finnish patents granted to Finnish firms by the National Board of Patents during the 1990s have been linked to the innovation database as well as the number of firm employees and some data on firm financials.

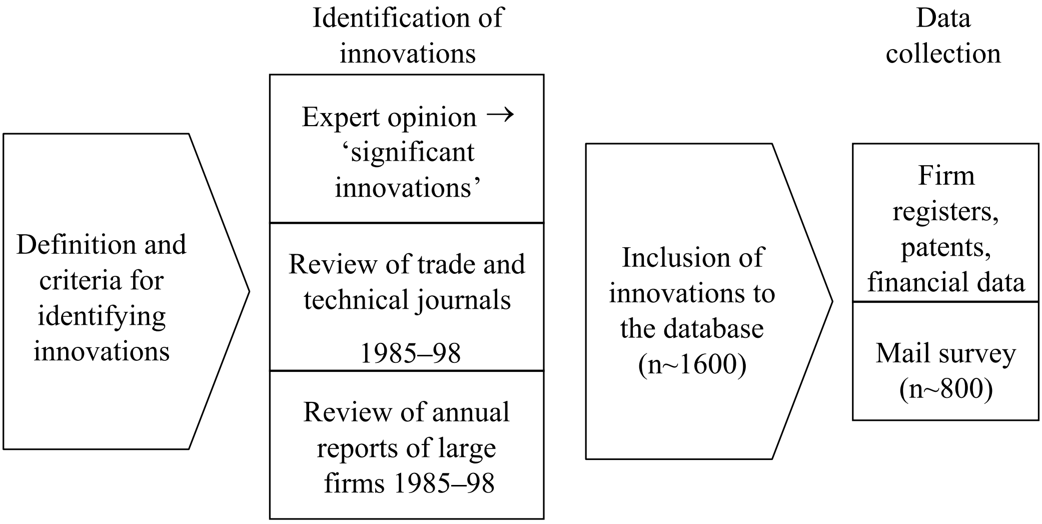

Figure 6. The methodology used in data collection.

Most of the innovations included in this study were identified through literature reviews. 18 trade and technical journals from the period 1985–98 have been systematically reviewed . In order to follow carefully the chosen definition, the focus has been on more formal accounts describing the innovations and containing some mention of their novelty as well as the name of the firm responsible for the market introduction of the innovation. The cost of applying rather strict selection criteria has been a relatively low number of observations.

Close to 200 additional innovations originated from expert interviews. A group of experts was asked to list the most significant Finnish innovations in their fields that were commercialised during the period in question. These innovations had to fulfil definitions comparable to those used in the literature reviews. A third source of innovations in the Sfinno data was the annual reports of large firms and concerns. The motivation for including this third source has been the central role of large firms in the Finnish economy - especially in the important forestry-based, metal products and engineering industries. Moreover, it has been argued that innovations originating from large firms might be underrepresented in trade journals (Audretsch, 1995). Large firms were selected by their R&D intensity and patenting. This exercise resulted in some 200 additional innovations being included in the Sfinno data.

For each innovation, the database includes the name of the innovation, a description of the innovation, the product class of the innovation and the innovator firm. After the identification of the various innovations, a survey questionnaire on the particular innovation in question and the innovation process was sent in case a relevant respondent could be identified. Around 1300 questionnaires were sent in total and the response rate turned out to be above 60 per cent. The questionnaire included questions on the origin and sectoral use of the innovation, R&D collaboration, public support and the commercial significance of the innovation. The empirical analysis outlined here is based on a sample of the survey data.

4.2.3 Issues related to the Sfinno database

The methodology and criteria used in gathering data for this study pose some problems. First of all, due to the definitions used in the data collection, the focus is on product innovations. However, as noted in section 2.3, the classification of innovations into product and process innovations depends on the perspective (see, e.g., Archibugi et al., 1994). An innovation can be a product innovation for its manufacturer but a process innovation for the adopter of the innovation. Thus also some process innovations are included in the data. In addition, many product innovations rely on process innovations. For example, in the paper industry it is often a question of developing new production methods, which in turn make it possible to produce new products. Therefore product innovations often implicitly include also process innovations. The point is that the classification of innovations into product and process innovations is not straightforward. Since the data at hand is not based on the systematic collection of carefully defined process and product innovations, the issue of product versus process innovation is not taken up in this study. However, it should be noted that the focus has been on commercialised innovations. As a result, non-commercialised innovations developed for a firm's own use are completely excluded in the data.

One common problem related to the object approach is that the underlying population of innovations is unknown. This means that the usual statistical sampling procedures are not available. There is no direct way to check how representative the collected data is, which makes it difficult to generalise the results. It is important to try to choose the data sources (for example the journals) so that various types of firms have the same probability of their innovations being included (OECD, 1997 and Kleinknecht, 1993). One way to get a rough idea of the coverage of the data is to compare it with data on other innovation indicators. These comparisons are, however, somewhat arbitrary, since each indicator is used to measure a different aspect of innovative activity and their distribution across, e.g., industries or size classes are not even expected to be the same.

The Sfinno data has been compared to both data on patents (Palmberg et al., 2000) and the Finnish CIS innovation surveys (Leppälahti, 2000). These comparisons did not reveal any illogical differences. In small firm size classes (under 100 employees), the share of innovations exceeded the share of patents and in large firm size classes (over 1000 employees), vice versa. This may be due to the cost of patenting. Large firms often have the bureaucracy needed for patenting in place, whereas small firms may see the application procedure as too laborious and costly. Compared to the CIS surveys, the Sfinno data appeared to include relatively more high-tech innovations located in the capital region, with a higher degree of novelty. This result also seems logical, since in the collection of the Sfinno data the emphasis was on more significant innovations.

It should also be noted that even though the Sfinno data is not a proper statistical sample over a well-defined population, it does not necessarily mean that the structures identified by the data are false. The key issue is whether the data is likely to reflect an accurate enough description of the structures underlying the phenomenon in question.

When it comes to the measurement of innovation, the data collection methodologies used often lead to a trade-off between the desired statistical properties of the data and obtaining innovation-level data. If statistical properties are emphasised, the data is collected at the firm level. The target population of firms is rather easy to define and available firm registers provide the frame population for the sampling. Therefore the usual statistical sampling procedures can be used in a rather straightforward manner. However, when the analysis in question requires data at the innovation level, it is much more difficult to design a sampling procedure fulfilling the criteria for the desired statistical properties. First of all, it is not self-evident what constitutes the underlying population of innovations. Even if the underlying target population could be clearly defined, it would be almost impossible to construct a suitable frame population that could form a basis for the sampling.

Comparisons between the CIS and Sfinno data might clarify the issue. The CIS survey contains firm-level data collected using proper statistical methodology. It provides a statistically well-grounded basis for studying firms' aggregate innovative activities. However, as mentioned in the introduction, with aggregate firm-level data it is not possible to say anything about innovation-level issues like the relationship between the innovation process and its outcome. The Sfinno data in turn provides innovation-level data, but it is not based on usual statistical sampling procedures.

Lastly, the use of three different sources for the identification of innovations can cause some bias in the data. Literature reviews and expert interviews are likely to be close enough to be incorporated into the same data set - especially since the large majority of innovations were identified from literature reviews and only a small fraction from interviews. The possible problem is caused by innovations identified from annual reports. First of all, only the annual reports of large, R&D-intensive companies were reviewed. This means that one subgroup of firms was covered more carefully than others, which obviously could have caused bias in the data. Secondly, a somewhat different methodology was used. R&D managers or other key persons were asked to choose the most significant innovations from a list of product launches collected from the firm's annual reports. These innovations have thus entered the database through the subjective selection of the firms themselves. However, only some 200 innovations of the total 1600 have been identified through annual reports. The statistical analyses were done both with and without this group of innovations and no signs of any bias were found.

4.2.4 Description of the Sfinno survey sample

The empirical analysis was based on a sample of the Sfinno survey data. The sample consists of 768 innovations. Innovations commercialised before 1980 and those with almost empty questionnaires (12 innovations) were subtracted from the original 818 innovations as well as 5 innovations, the development process of which had been interrupted.

Among the 768 innovations included in the sample, there were some 30 innovations for which the commercialisation year was missing. In these cases the commercialisation year was imputed using the available information related to the innovation's life cycle. In the questionnaire the respondents were asked to fill in the years when the basic idea was proposed, the development stage began, the first prototype was finished and commercialisation began. If the commercialisation year was missing, but some other years were filled in, those were used in the imputation. For example, if the year when the first prototype was finished was known, then the sample average of the time from the first prototype to the commercialisation was counted and the commercialisation year was estimated to be the year when the first prototype was finished plus this sample average.

In addition to the Sfinno survey sample, also the patent data on Finnish patents have been used. This patent data consists of Finnish patents granted to firms present in the Sfinno data by the National Board of Patents during the 1990's. Moreover, the size of the firm at the time of the innovation's commercialisation has been linked to the survey data. The firm size was measured by the number of employees. If the number of employees at the time of the innovation's commercialisation was not known, the closest available figure was used.

The distinction between radical and incremental innovations is based on two survey questions related to the novelty of innovations. The first question deals with technological novelty from the firm perspective and the second with novelty from the markets perspective. If an innovation is technologically entirely new to the firm and new on the global markets it is considered radical. Otherwise an innovation is considered incremental (involving a significant or minor improvement, which is or is not new to the global markets). The classification of innovations into radical and incremental innovations is thus based on survey answers.

This distinction between radical and incremental innovations is not totally in accordance with the corresponding theoretical definitions. In the theoretical discussion, the radicalness and the novelty of an innovation are separated (see section 2.4), whereas the above empirical distinction combines these two aspects. In other words, the theoretical definition of a radical innovation refers only to the technological aspect of the innovation without taking into account whether the innovator has actually developed a technologically new product or process or whether the innovator has just adapted a radical innovation that has already been implemented somewhere else . Therefore the theoretical definition of a radical innovation includes both the development and diffusion of radical innovations. In this study the objective was to study the development processes underlying radical versus incremental innovation. Therefore the adaptation of technologically new products or processes is related to the class of incremental innovations. The development process of practically all the innovations studied here has involved firms' own research and development, which indicates that also the adaptation of innovations requires development work. This speaks in favour of the argument presented in section 3.6.2, that transferring and utilising knowledge is not automatic.

48 per cent of innovations in the data set are radical according to the criteria defined above. This figure is quite different from those indicated by literature-based studies carried out in other countries. Acs and Audretsch (1993) report that in the US data of 4938 innovations commercially introduced in the United States in 1982, 87 per cent of the innovations were modest improvements designed to update existing products and none of the innovations belonged to the highest level of significance, which had been defined as "establishes whole new categories"[3]. Kleinknecht et al. (1993) in turn found that according to the literature-based study covering Dutch innovations reported in selected journals in 1989, only 3.6 per cent of innovations were new or strongly altered products. Austrian evidence from a literature-based study pointed out that 17.5 per cent of innovations were completely new or basically changed products (Fleissner et al., 1993). In Ireland Cogan (1993) divided the novelty of innovations into three classes: completely new, modestly improved and differentiation of existing products. According to his results, only 4 of the 486 product innovations were completely new.

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[3] In total there were four different significance levels: establishes whole new categories; first of its type on the market in existing categories; a significant improvement in existing technology; and modest improvement designed to update existing products.

Even though the somewhat different data collection methods, different time periods and definitions used make it difficult to compare the results of different literature-based studies, the Finnish figure seems to differ considerably from those of other countries. One reason for this might be that only in Finland is the classification done based on survey questions that the innovators themselves have answered. In all the other studies mentioned above, the classification has been done either by researchers or by a third party. In the United States a telephone interview was done based on a subset of innovations, in which the innovators were asked to rate the significance of their innovations. In general the innovators tended to give higher ratings than a third party, suggesting that either the innovators have an overly optimistic view of the significance of their innovations or that the third party has underrated the innovations.

Another explanation might be that the criteria used in the collection of Sfinno data have been stricter than in most of the other studies. For example, in the Dutch study, all product announcements reported in trade journals were accepted, while in the collection of the Sfinno data, emphasis was put on technological novelty. A product was regarded as an innovation if it was a technologically new or enhanced product from the firm perspective.

The complexity of innovations is categorised here based on a classification scheme developed by Jukka Hyvönen (see Appendix 1). The classification scheme is an applied version of the one used by Kleinknecht et al. (1993). Innovations are divided into four different classes according to their artefactual and developmental complexity. Artefactual complexity refers to the structure of the innovation. For example, a paper machine is of high artefactual complexity, while a hammer is of low artefactual complexity. Developmental complexity in turn refers to the knowledge base required in the development. High developmental complexity means the combination of several different disciplines, while low developmental complexity stands for the knowledge base originating mainly from one discipline. In this work, the first two and the last two classes are put together, since there are relatively few observations in the extreme classes. As a result, innovations are divided into high and low complexity classes. High complexity innovations have high developmental complexity and high or medium artefactual complexity, whereas low complexity innovations have low developmental complexity and medium or low artefactual complexity. As mentioned above, for simplicity high complexity innovations are called in this study complex innovations and low complexity innovations are called simple innovations.

In addition to Kleinknecht et al. (1993), also Fleissner et al. (1993) and Cogan (1993) have analysed the complexity of innovations. The criteria used for complexity are all based on Kleinknecht's classification into high, medium and low complexity. In all three studies, relatively few innovations fall into the class of high complexity (2.5 %, 16.7 % and 0 % respectively), which is in line with the Sfinno data. According to the original four-scale classification, only 2.7 per cent of innovations were of the highest complexity, corresponding to Kleinknecht's class of high complexity.

It should be noted that the distinctions between complex and radical innovations are independent of each other. In other words, a complex innovation may be a modest improvement to an existing complex product, whereas a radical innovation can be a simple product like a vacuum pump for wine. According to the data, 51 per cent of complex innovations are also radical, while for the simple innovations the corresponding figure is 45 per cent. The Spearman correlation coefficient between the variables *COMP* and *RADICAL* was 0.06.

Explanatory variables and their construction are presented in Table 1. Descriptive statistics of the variables can be found in Table B.1 in Appendix B. The non-response to the survey questions underlying these variables was usually below one per cent and only in a few cases between two and four per cent. All these missing answers were imputed using the information provided by other questions or the sample averages. Answers were also checked for possible inconsistencies and the data was checked for duplicates.

The distribution of the significance of different factors as sources of an original innovation idea is presented in Figure 7. Values 2 and 3 have been regarded as important and values 0 and 1 as not important.

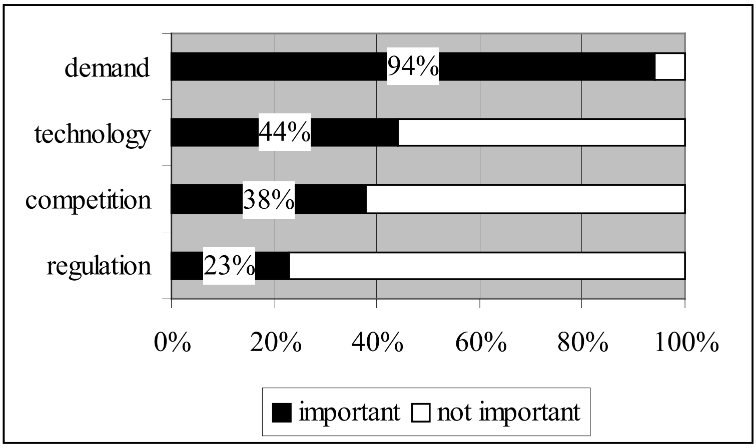

Figure 7. Importance of different factors as sources of original innovation ideas.

As can be seen, demand has been an important source of original innovation ideas for practically all the innovations. This reflects the theoretical discussion related to the integration of demand-pull and science-push hypotheses. The figure seems to confirm the idea that market need is a necessary but not sufficient condition for an innovation to occur. In terms of the relative importance of different sources for the origin of innovations, the survey questions underlying the variable *DEMAND* are, however, somewhat ill-structured. Instead of simply asking the importance of demand, the focus should have been on **changes** in the demand conditions. It is rather self-evident that profit-seeking firms regard the existence of demand as a precondition for the development of new products. Since there is little variation in the variable DEMAND across innovations, the variable was excluded from further analysis[4].

The distribution of the importance of different collaborative partners during the development process is presented in Figure 8. Values 2 and 3 have been regarded as important and values 0 and 1 as unimportant.

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[4] It was checked in the estimations that the variable *DEMAND* was redundant in the regressions.

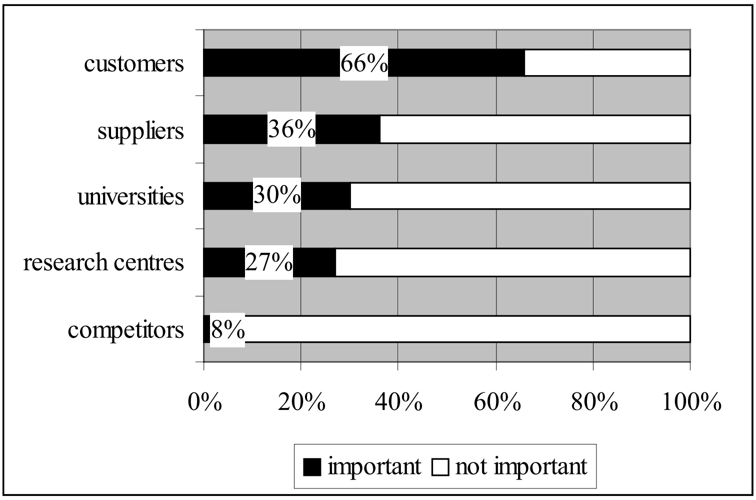

Figure 8. Importance of different collaborative partners.

Here again the role of customers is highlighted. Customers are by far the most typical collaborative partners regarded as important during the innovation process. Meanwhile the horizontal collaboration with competitors seems to be insignificant. So few respondents regarded the collaboration with competitors as important that excluding horizontal collaboration from further analysis is justified[5].

[5] It was also checked in the estimations that the variable *HORIZONT* was redundant in the regressions.

Table 1. Variables used in the empirical analysis.

Dependent variables	
COMP	A dummy variable, which equals one if the innovation has high developmental complexity and high or medium artefactual complexity or 0 otherwise.
RADICAL	A dummy variable, which equals one if the innovation is technologically entirely new to the firm and new on the global markets or 0 otherwise.
Explanatory variables	
<u>Sources of the original innovation idea</u>	Higher of the two scores given to questions asking the importance of:
TECH	new scientific breakthroughs or new technologies
DEMAND	observation of a market niche or customer demand
COMPTION	intensification of price competition or threat posed by rival innovation
REGLTION	regulations, legislation and standards or environmental factors
	to the origin of innovation (0=not impotant, 1=minor importance, 2=important, 3=very important).
<u>Type of development work required</u>	A dummy variable, which equals 1 if:
CORETECH	productisation of a particular core technology
SYSTEM	development or combination of different components or modules
METHOD	development of production methods
OTHER	productisation of service concepts or other type of development
	best describes the type of development work required in the innovation process or 0 otherwise.

External collaboration	Highest of the scores given to questions asking the importance of:
CUSTOMER	collaboration with domestic or foreign customers
UNIV	collaboration with domestic or foreign universities
RCENTRE	collaboration with VTT, domestic or foreign research centres
VERTICAL	Collaboration with domestic or foreign suppliers
HORIZONT	collaboration with domestic or foreign competitors.
	(0=not important, 1=minor importance, 2=important, 3=very important)
Public funding	A dummy variable, which equals 1 if:
PROGRAM	public funding has been granted to the innovation's development and a technology programme has been important as regards collaboration associated with the innovation's development
SUBSIDY	public support without participation in a technology programme has been obtained for the innovations development
	or 0 otherwise.
Knowledge base	
DIVERSIF	Number of the main patent classes in which the innovator has been granted at least one patent.

<u>Technological environment</u>	A dummy variable, which equals 1 if the product class of the innovation belongs to one of the following sectors:
FOOD	food, beverage, tobacco
PAPER	wood, wood products, pulp, paper
CHEMICAL	chemicals, rubber, plastics, oil
METAL	basic metals, metal products
MACHINE	machinery, equipment
ELECTRO	electrotechnical products
SOFTA	software
OTHER	other
	or 0 otherwise.
<u>Demand conditions</u>	
GROWTH	Average growth rate of the product class of the innovation over the 5 years preceding the commercialisation of the innovation.
<u>Size of the firm</u>	
SIZE	A variable, which equals 1 if the number of employees at the time of the commercialisation of the innovation is below 10; 2 if the number of employees is between 10 and 99; 3 if the number of employees is between 100 and 999; and 4 if the number of employees is equal to or over 1000.

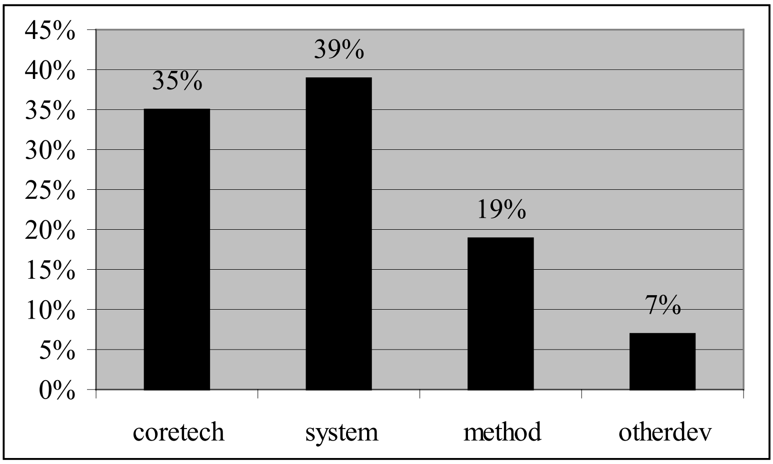

Figure 9. The type of development work most closely related to the innovation process.

The distribution of the type of development work most closely related to the innovation process is presented in Figure 9. Productisation of service concepts has been related to so few innovation processes that the productisation of service concepts and other types of development work are combined into a class called *OTHERDEV*. *SYSTEM* is left as a reference group in the econometric models.

Public funding has been granted in the development of 67 per cent of the innovations. This seems a rather high figure, but it should be noted that all the innovations considered are successful innovations in the sense that the development process has not failed. Public funding is divided between technology programmes and other subsidies so that for 27 per cent of the innovations the subsidy was related to a technology programme and for 42 per cent of the innovations public funding has been in the form of other subsidies. Here it should be noted that the question that has been used to construct the technology programme variable is somewhat problematic. The exact question is: *Has a public technology programme been important as regards collaboration associated with the innovation's development?* If public funding has been granted to the innovation's development and the answer to the question is yes, then the technology programme variable gets a value of 1 and 0 otherwise. Therefore the technology programme variable rather describes those innovations processes for which the goal of inducing collaboration has truly materialised.

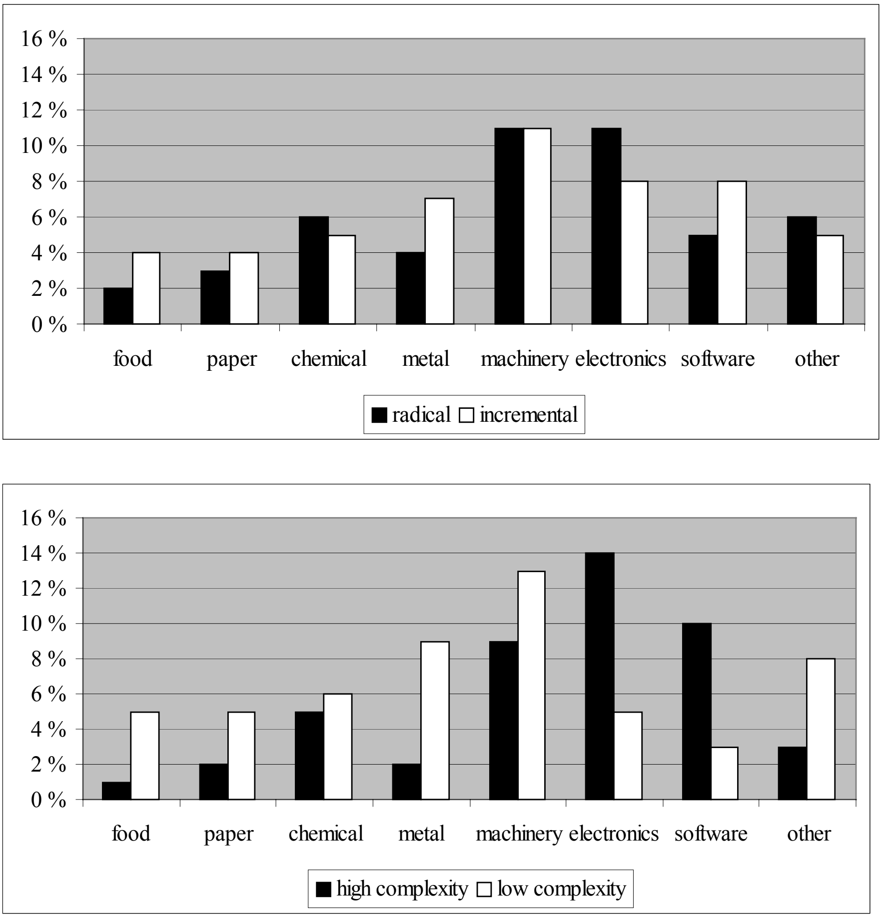

Figure 10. Distributions of radical and incremental innovations and high complexity and low complexity innovations by product class.

Figure 10 presents the distributions of radical and incremental innovations as well as the distributions of high complexity and low complexity innovations according to the product class of the innovation. There seems to be considerable differences in the distributions depending on the technological nature of the innovation - especially between high and low complexity innovations. This indicates that the technological environment in which the innovation is developed actually does matter.

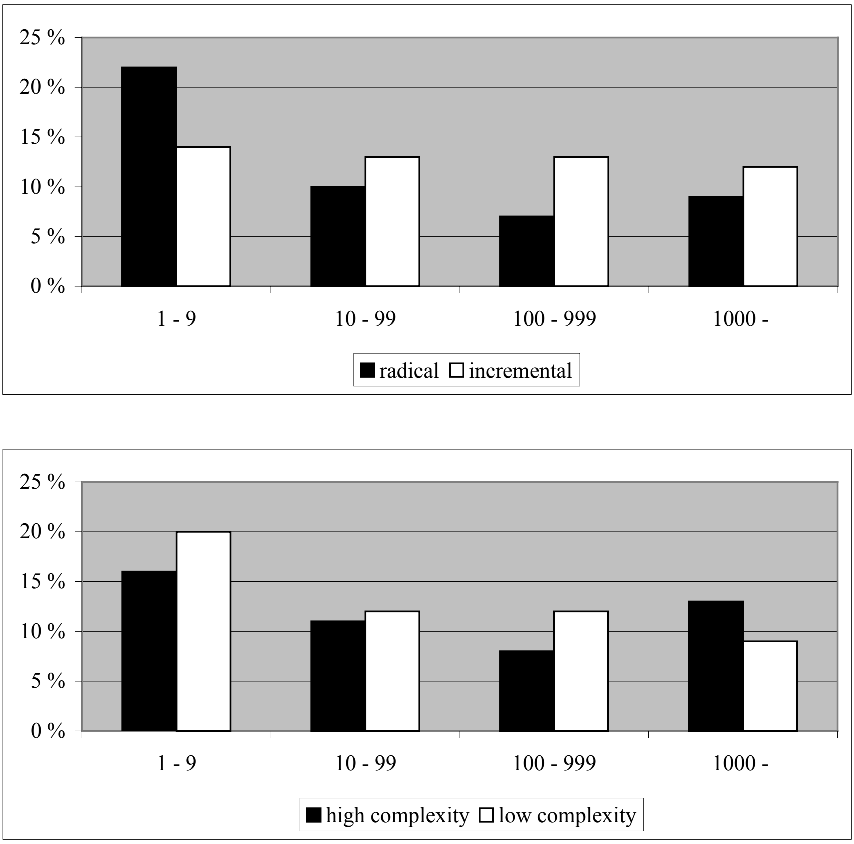

Figure 11. Distribution of innovations according to the number of employees at the time of commercialisation of the innovation.

The distributions of radical and incremental innovations as well as the distributions of high complexity and low complexity innovations according to the number of employees at the time of commercialisation of the innovation are presented in Figure 11. It seems that small firms develop relatively more radical innovations, while large firms develop relatively more high complexity innovations. All in all, Figures 10 and 11 justify the inclusion of product group dummies and the variable *SIZE* as control variables in the econometric models.

4.3 Econometric modelling

4.3.1 Probit models

Since the dependent variables describing the radicalness and complexity of innovation are discrete and qualitative variables, empirical analyses were done in the framework of probability models. Probability models can be divided into binomial and multinomial types depending on whether the outcome is a choice between two or more than two alternatives (Greene, 1997). In this study the dependent variables *COMP* and *RADICAL* are binary (0/1) variables, which specified the framework to binomial probability models. In practise this means that the probability of the development process resulting in an innovation of a specific type is assumed to be related to the characteristics of the development process.

The basic structure of binomial probability models can be described in the following way. Let y be a binary variable, which can take the value of 1 or 0 and let $\mathbf{x} = (x_1, x_2, ..., x_k)'$ be a vector of k explanatory variables. It is assumed that the explanatory variables are related to the probability of getting either $y_i=1$ or $y_i=0$ such that:

$$\begin{aligned} &\text{Prob}(y_i = 1 \mid \mathbf{x}_i) = \text{F}(\boldsymbol{\beta}'\mathbf{x}_i) \\ &\text{Prob}(y_i = 0 \mid \mathbf{x}_i) = 1 - \text{F}(\boldsymbol{\beta}'\mathbf{x}_i), \quad i = 1,..., \text{n}. \end{aligned} \tag{4.1}$$

$\boldsymbol{\beta}$ is the (k x 1) parameter vector reflecting the impact of changes in explanatory variables on the probability. Function *F*(.) usually takes the form of either a cumulative distribution function of the standard normal distribution (probit model) or a cumulative distribution function of the logistic distribution (logit model).[6] Greene (1997) states that it is difficult to justify the choice of one distribution or another on theoretical grounds and for the intermediate values of $\boldsymbol{\beta}'\mathbf{x}_i$ the two distributions tend to give similar probabilities. Since the analysis in this study includes also estimation of bivariate models the standard normal distribution has been chosen for the empirical analysis. Equation 4.1 can now be specified by adding the standard normal distribution.

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[6] Linear probability models are not taken up due to the number of shortcomings they have compared to probit or logit models.

$$\text{Prob}(y_i = 1 | \mathbf{x}_i) = \Phi(\boldsymbol{\beta}'\mathbf{x}_i) = \int_{-\infty}^{\boldsymbol{\beta}'\mathbf{x}_i} \frac{1}{\sqrt{2\pi}} e^{-t_i^2/2}\, dt_i = g(\mathbf{x}_i) \quad (4.2)$$

When interpreting the parameter estimates of probit models, it should be borne in mind that since it is a question of a nonlinear model, the parameters are not necessarily the marginal effects as in linear regression models (Greene, 1997). The marginal effect of an explanatory variable *l* is the following

$$g_l(\mathbf{x}) = \frac{\partial g_l(\mathbf{x})}{\partial x_l} = \phi(\boldsymbol{\beta}'\mathbf{x})\,\beta_l, \quad (4.3)$$

where $\phi(.)$ is the density function of the standard normal distribution. Clearly the parameter estimates cannot be interpreted as the marginal effects. Parameter estimates indicate whether the effect of explanatory variables on the probability is positive or negative, but not necessarily the magnitude of the effect. The marginal effects vary with all the values of explanatory variables **x**. A logical candidate to examine the marginal effects would be to evaluate the marginal effect at every observation and compute the sample average of these individual marginal effects.

$$\overline{g_l(\mathbf{x})} = \frac{1}{n}\sum_{i=1}^{n} g_l(\mathbf{x}_i) = \beta_l \frac{1}{n}\sum_{i=1}^{n} \phi(\boldsymbol{\beta}'\mathbf{x}_i) \quad (4.4)$$

Since $g_l(\mathbf{x})$ is a non-linear function of **x** equation (4.4) is not equal to the marginal effect computed at the sample mean of vector **x (**Vartia and Koskimäki, 2001**)**.[7] That is

$$\overline{g_l(\mathbf{x})} \neq g_l(\overline{\mathbf{x}}), \quad (4.5)$$

[7] Jensen's inequality states that if g(x) is a concave function of x, then g(E[x]) ≥ E[g(x)].

where $g_l(\overline{\mathbf{x}}) = g_l(\frac{1}{n}\sum_{i=1}^{n} x_{1i}, \frac{1}{n}\sum_{i=1}^{n} x_{2i}, ..., \frac{1}{n}\sum_{i=1}^{n} x_{ki})$. However since the function $g_l(\mathbf{x})$ is continuous and twice differentiable it can be approximated by quadratic Taylor series approximation. Let f: $R^k \to R$ be a continuous twice differentiable function and $\mathbf{x}$ be a vector in R^k, $\mathbf{x}_i = (x_{1i}, x_{2i}, ..., x_{ki})$, i=1, ..., n. Then a quadratic Taylor series approximation of f at $\mathbf{x}^0$ is of the form:

$$f(\mathbf{x}) \cong f(\mathbf{x}^0) + \left[\frac{\partial f(\mathbf{x}^0)}{\partial \mathbf{x}}\right]'(\mathbf{x} - \mathbf{x}^0) + \frac{1}{2}(\mathbf{x} - \mathbf{x}^0)'\left[\frac{\partial^2 f(\mathbf{x}^0)}{\partial \mathbf{x} \partial \mathbf{x}'}\right](\mathbf{x} - \mathbf{x}^0). \quad (4.6)$$

If the sample average of vector $\mathbf{x}$ is used for the expansion point $\mathbf{x}^0$ i.e. $\mathbf{x}^0 = \overline{\mathbf{x}}$ we get

$$f(\mathbf{x}) \cong f(\overline{\mathbf{x}}) + \left[\frac{\partial f(\overline{\mathbf{x}})}{\partial \mathbf{x}}\right]'(\mathbf{x} - \overline{\mathbf{x}}) + \frac{1}{2}(\mathbf{x} - \overline{\mathbf{x}})'\left[\frac{\partial^2 f(\overline{\mathbf{x}})}{\partial \mathbf{x} \partial \mathbf{x}'}\right](\mathbf{x} - \overline{\mathbf{x}}), \quad (4.7)$$

which gives (Vartia and Koskimäki, 2001)

$$\begin{aligned} \overline{f(\mathbf{x})} &= \frac{1}{n}\sum_{i=1}^{n} f(\mathbf{x}_i) \\ &\cong \frac{1}{n}\sum_{i=1}^{n}\left(f(\overline{\mathbf{x}}) + \left[\frac{\partial f(\overline{\mathbf{x}})}{\partial \mathbf{x}}\right]'(\mathbf{x}_i - \overline{\mathbf{x}}) + \frac{1}{2}(\mathbf{x}_i - \overline{\mathbf{x}})'\left[\frac{\partial^2 f(\overline{\mathbf{x}})}{\partial \mathbf{x} \partial \mathbf{x}'}\right](\mathbf{x}_i - \overline{\mathbf{x}}) \right) \quad (4.8) \\ &= f(\overline{\mathbf{x}}) + \frac{1}{2}\sum_{j=1}^{k}\sum_{s=1}^{k} \frac{\partial^2 f(\overline{\mathbf{x}})}{\partial x_j \partial x_s} \text{cov}(x_j, x_s) = f(\overline{\mathbf{x}}) + \Delta. \end{aligned}$$

If Δ is small $f(\overline{\mathbf{x}})$ is approximately equal to $\overline{f(\mathbf{x})}$.

Let us return to equations (4.3) and (4.4). It was suggested that a logical candidate to examine the marginal effect of explanatory variable l would be to evaluate the marginal effect at every observation and compute the sample average of these individual marginal effects, which is represented in equation (4.4). Based on equation (4.8)

$$\overline{g_l(\mathbf{x})} \cong g_l(\bar{\mathbf{x}}) + \frac{1}{2}\sum_{j=1}^{k}\sum_{s=1}^{k}\frac{\partial^2 g_l(\bar{\mathbf{x}})}{\partial x_j \partial x_s}\text{cov}(x_j, x_s). \tag{4.9}$$

Since the covariances of the explanatory variables should be small and the curvature of function g(**x**) is usually small close to the mean of **x,** the latter term is generally negligible. That is, the mean of the marginal effects is roughly equal to the marginal effect evaluated at the sample mean and the choice between the two is largely a matter of convenience. Usually the marginal effect evaluated at the sample mean is used, since it is often computationally easier. This method was also chosen in this study.

For the binary explanatory variable $x_{d,}$ the appropriate marginal effect is the following:

$$\text{Prob}(y = 1 \mid \bar{\mathbf{x}}_*, x_d = 1) - \text{Prob}(y = 1 \mid \bar{\mathbf{x}}_*, x_d = 0), \tag{4.10}$$

where $\bar{\mathbf{x}}_*$ denotes the sample means of all the other explanatory variables except x_d (Greene, 1997).

As the equation 4.2 is nonlinear, the estimation of the parameter vector $\boldsymbol{\beta}$ is based on the method of maximum likelihood. Each observation is treated as a single draw from the Bernoulli distribution, which leads to the following likelihood function (Greene, 1997)

$$L = \prod_{i=1}^{n}\left[\Phi(\boldsymbol{\beta}'\mathbf{x}_i)\right]^{y_i}\left[1 - \Phi(\boldsymbol{\beta}'\mathbf{x}_i)\right]^{1-y_i}. \tag{4.11}$$

Maximisation of this function requires an iterative solution.

Often the discrete dependent variable models are presented in the form of index function models. In this representation it is assumed that there is an underlying response variable y* defined by the regression relationship (Maddala, 1987, p. 22)

$$y_i^* = \boldsymbol{\beta}'\mathbf{x}_i + \varepsilon_i, \tag{4.12}$$

where ε_i is a random disturbance describing the unsystematic part of the regression equation.

The response variable y* is an unobservable latent variable (Greene, 1997). The observed binary variable y is defined by

$$\begin{aligned} y_i &= 1 \quad \text{if } y_i^* > 0 \\ y_i &= 0 \quad \text{if } y_i^* \leq 0. \end{aligned} \tag{4.13}$$

For example, the two endogenous variables in this study, *COMP*=y^1 and *RADICAL*=y^2, can be described in terms of two continuous latent variables, y^1* and y^2*. Latent variable y^1* can be thought of as measuring the complexity of innovation. If it gets a value above zero, the innovation is named complex and simple otherwise. Similarly, the latent variable y^2* can be thought of as measuring the radicalness of innovation so that innovations for which this variable gets values above zero are regarded as radical and others as incremental.

If it is assumed that vector $\varepsilon_i \sim N(0,1)$ for all i = 1, ..., n we get:[8]

$$\begin{aligned} &\text{Prob}(y_i = 1 | \mathbf{x}_i) = \text{Prob}(y_i^* > 0 | \mathbf{x}_i) = \text{Prob}(\varepsilon_i > -\boldsymbol{\beta}' \mathbf{x}_i | \mathbf{x}_i) \\ &= 1 - \Phi(-\boldsymbol{\beta}' \mathbf{x}_i) = \Phi(\boldsymbol{\beta}' \mathbf{x}_i), \end{aligned} \tag{4.14}$$

which is equal to (4.2) and we get the same maximum likelihood function as in (4.11).

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[8] The assumption of unit variance is an innocent normalisation since y is 0 or 1 depending only on the sign of y* not on its scale (Greene 1997, 880). We could think of starting with $\hat{y}_i^* = \hat{\boldsymbol{\beta}}' \mathbf{x}_i + \hat{\varepsilon}_i$, where $\hat{\varepsilon}_i \sim N(0, \sigma_\varepsilon^2)$. Multiplying both sides by $1/\sigma_\varepsilon$ leads to $\frac{1}{\sigma_\varepsilon}\hat{y}_i^* = \frac{1}{\sigma_\varepsilon}\hat{\boldsymbol{\beta}}' \mathbf{x}_i + \frac{1}{\sigma_\varepsilon}\hat{\varepsilon}_i$, which can be rewritten as $y_i^* = \boldsymbol{\beta}' \mathbf{x}_i + \varepsilon_i$, $\varepsilon_i \sim$ N(0, 1).

Using the above notation, the two single equation probit models to be estimated in this study can be presented as the following index function models. The index function model for complexity is of the form:

$$y^{1*} = \boldsymbol{\beta}_c' \mathbf{x}_i + e_i, \tag{4.15}$$

and for the radicalness of the form:

$$y^{2*} = \boldsymbol{\beta}_r' \mathbf{x}_i + v_i. \tag{4.16}$$

Vector $\mathbf{x}_i$ is a (23 x 1) vector consisting of the explanatory variables defined in Table 1 excluding the variables *DEMAND* and *HORIZONT* as well as the reference groups of *SYSTEM* and *MACHINE* plus a constant, $e_i \sim N(0,1)$ for all i = 1, ..., n and $v_i \sim N(0,1)$ for all i = 1, ..., n.[9]

4.3.2 Tackling heteroscedasticity

In cross-section data heteroscedasticity is often present;that is, the variance of the error term is not constant across observations. In this study the variance of the error terms can differ, for example, between different industries or size classes or depending on the type of development work required. In the classical linear regression model heteroscedastic disturbances do not cause any fundamental problems related to the least squares estimators. In the presence of heteroscedasticity the least squares parameter estimates of a linear regression model are inefficient but still unbiased and consistent. When it comes to binary probability models, the situation is unfortunately different. Yatchew and Griliches (1984) show that in the setting of the probit and logit models the maximum likelihood estimators are inconsistent and the covariance matrix is inappropriate if the disturbances in the underlying regression are heteroscedastic.

[9] See footnote 8.

In this study the presence of heteroscedasticity is examined using the general formulation presented by Harvey (1976). Adding heteroscedasticity to probit models presented in (4.15) and (4.16) we get

$$\begin{aligned} y_i^{1*} &= \boldsymbol{\beta}_c' \mathbf{x}_i + e_i, \\ \mathrm{Var}(e_i) &= \left[\exp(\boldsymbol{\theta}_c' w_i^c)\right]^2 \end{aligned} \tag{4.17}$$

and

$$\begin{aligned} y_i^{2*} &= \boldsymbol{\beta}_r' \mathbf{x}_i + v_i, \\ \mathrm{Var}(v_i) &= \left[\exp(\boldsymbol{\theta}_r' w_i^r)\right]^2 \end{aligned} \tag{4.18}$$

respectively. Vectors $\mathbf{w}^c$ and $\mathbf{w}^r$ include some of the k explanatory variables (x_1, x_2, ..., x_k) except the constant. Variables were chosen according to their statistical significance. When the heteroscedasticity is taken into account the likelihood function to be maximised is modified to:[10]

$$L = \prod_{i=1}^{n} \left[\Phi\left(\frac{\boldsymbol{\beta}' \mathbf{x}_i}{\exp(\boldsymbol{\theta}' \mathbf{w}_i)}\right) \right]^{y_i} \left[1 - \Phi\left(\frac{\boldsymbol{\beta}' \mathbf{x}_i}{\exp(\boldsymbol{\theta}' \mathbf{w}_i)}\right) \right]^{1-y_i} . \tag{4.19}$$

The presence of heteroscedasticity can be tested using the usual likelihood ratio, Lagrange multiplier or Wald tests for H_0: $\boldsymbol{\theta} = 0$. The restricted log-likelihood is the log-likelihood of the basic probit model assuming homoscedasticity.

4.3.3 Endogeneity of public funding

The explanatory variables used in this study (described in Table 1) include the public funding variables of *PROGRAM* and *SUBSIDY*. The problem with these variables is that they may be endogenous. It is unlikely that public funding is randomly allocated to different innovation projects. Instead, the organisations

[10] For simplicity, the superscripts 1 and *2* of y and subscripts *c* and *r* of $\boldsymbol{\beta}$, $\boldsymbol{\theta}$ and **w** are excluded from the notation.

responsible for the allocation of funds use the available information to select the projects to be funded according to some predefined selection criteria. If the selection criteria are such that an innovation project that is more likely to result in a specific type of innovation is more likely to get public funding, the single equation probit model is not appropriate. This happens if the selection criteria are based on factors that also affect the likelihood of a specific type of innovation.[11]

If, for example, public funding is directed towards co-operative innovation projects and co-operative innovation projects are likelier to produce complex innovations than simple ones, the effect of public funding in a single equation probit will be biased upwards. The effect of public funding will represent a bundling of pure public funding effects (meaning that public funding enables firms to develop certain types of innovations) and differences in getting public funding for different types of innovation projects.

In order to analyse this possible selection problem, the two variables describing public funding, *PROGRAM* and *SUBSIDY,* are combined into one variable: *FUNDING,* and a bivariate probit specification is used to analyse the endogeneity. At this stage it is assumed that the criteria used in selecting projects for technology programmes and allocating other types of public funding are similar enough with respect to the characteristics in question to be combined in one variable. This assumption is later given up by estimating two separate bivariate probit models in which the variable *FUNDING* is replaced by the variables *PROGRAM* and *SUBSIDY*.

First of all, a probit model has to be constructed that describes how the probability of getting public funding is related to the characteristics of the innovation project and the innovator. Let q* be an unobservable latent variable underlying a binary variable q, which takes the value 1 if the innovation project has got public funding and 0 otherwise. The index function model describing the relationship between q_i^* and the vector of explanatory variables $\mathbf{z}_i$ is of the form:

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[11] In reality, it is not only a question of public authorities allocating the money. It is also question of who applies for public funding in the first place.

$$q_i^* = \boldsymbol{\gamma}'\mathbf{z}_i + u_i, \qquad q_i = 1 \quad \text{if} \quad q_i^* > 0, \quad 0 \text{ otherwise}, \quad i = 1,...,n, \qquad (4.20)$$

where u is the random error term, $u_i \sim N(0,1)$.[12] γ is the unknown parameter vector and $\mathbf{z}_i$ the vector of m explanatory variables $\mathbf{z}_i = (z_{1i}, ..., z_{mi})'$.

In the bivariate probit specification, two equations with correlated disturbances are estimated simultaneously. Since endogeneity may be present in both single equation probit models (4.15) and (4.16), there are two bivariate probit models to be estimated:

$$\begin{aligned} y_i^{1*} &= \boldsymbol{\beta}_c'\mathbf{x}_i + e_i, \qquad y_i^1 = 1 \quad \text{if} \quad y_i^{1*} > 0, \quad 0 \text{ otherwise} \\ q_i^* &= \boldsymbol{\gamma}'\mathbf{z}_i + u_i, \qquad q_i = 1 \quad \text{if} \quad q_i^* > 0, \quad 0 \text{ otherwise} \end{aligned} \qquad (4.21)$$

and

$$\begin{aligned} y_i^{2*} &= \boldsymbol{\beta}_r'\mathbf{x}_i + v_i, \qquad y_i^2 = 1 \quad \text{if} \quad y_i^{2*} > 0, \quad 0 \text{ otherwise} \\ q_i^* &= \boldsymbol{\gamma}'\mathbf{z}_i + u_i, \qquad q_i = 1 \quad \text{if} \quad q_i^* > 0, \quad 0 \text{ otherwise.} \end{aligned} \qquad (4.22)$$

In (4.21) and (4.22) the upper equations are defined by (4.15) and (4.16) respectively. Only the vector $\mathbf{x}_i$ is not exactly the same as in (4.15) and (4.16), since the variables *PROGRAM* and *SUBSIDY* are omitted (the reason for this will be explained below). Vector $\mathbf{z}_i$ consists of the same variables as vector $\mathbf{x}_i$. The error terms are expected to follow a bivarite normal distribution with correlation coefficients ρ_1 and ρ_2, $(e_i, u_i) \sim N_2(0, 0, 1, 1, \rho_1)$ and $(v_i, u_i) \sim N_2(0, 0, 1, 1, \rho_2)$.

If the variable *FUNDING* were to be included as an explanatory variable in the complexity or radicalness equation, there should be at least one variable in vector $\mathbf{z}_i$, which is omitted from the same equation, that serves as an identifying instrument. Otherwise the two equation system is not identified. This instrument should be such that it is related with the variable *FUNDING* but not with the variables *COMP* and *RADICAL*. Within the limits of the available data no reliable instrument was, however, found. Therefore the bivariate probit models are

[12] See footnote 8.

estimated in the spirit of seemingly unrelated regressions (see Greene, 1997). That is, neither of the endogenous variables is included in the equations as explanatory variables and the possible endogeneity is analysed through the error terms. Significant correlation between the error terms of the two equations is an indication of endogeneity.

The chosen approach to two equation models does not provide an estimate of the effect of public funding on the probability of a complex or radical innovation. This highlights the consequences of the identification problem - a parameter estimate that is corrected for endogeneity cannot be estimated for the endogenous variable. In other words, the endogeneity and the effect of one endogenous variable on the other cannot be analysed simultaneously. However, the estimation of the two equation system in the spirit of seemingly unrelated regressions enables assessing whether endogeneity is an issue or not in the single equation specifications and how the possible endogeneity is reflected in the parameter estimates of other explanatory variables.

Equation (4.21) is used as an example in explaining the estimation procedure of bivariate probit models. Since the error terms of the two equations are correlated, bivariate normal distribution has to be used to calculate these probabilities. The probabilities of interest are now (Maddala, 1987, p. 123):

$$\begin{aligned}
\mathrm{P}_{11} &= \mathrm{Prob}(\mathrm{y}_i^1 = 1, \mathrm{q}_i = 1 \,|\, \mathbf{x}_i, \mathbf{z}_i) = \mathrm{Prob}(\mathrm{y}_i^{1*} > 0, \mathrm{q}_i^* > 0 \,|\, \mathbf{x}_i, \mathbf{z}_i) \\
&= \Phi_2(\boldsymbol{\beta}_c{}'\mathbf{x}_i, \boldsymbol{\gamma}'\mathbf{z}_i, \rho_1) \\
\mathrm{P}_{10} &= \mathrm{Prob}(\mathrm{y}_i^1 = 1, \mathrm{q}_i = 0 \,|\, \mathbf{x}_i, \mathbf{z}_i) = \mathrm{Prob}(\mathrm{y}_i^{1*} > 0, \mathrm{q}_i^* \leq 0 \,|\, \mathbf{x}_i, \mathbf{z}_i) \\
&= \Phi_2(\boldsymbol{\beta}_c{}'\mathbf{x}_i, -\boldsymbol{\gamma}'\mathbf{z}_i, -\rho_1) \\
\mathrm{P}_{01} &= \mathrm{Prob}(\mathrm{y}_i^1 = 0, \mathrm{q}_i = 1 \,|\, \mathbf{x}_i, \mathbf{z}_i) = \mathrm{Prob}(\mathrm{y}_i^{1*} \leq 0, \mathrm{q}_i^* > 0 \,|\, \mathbf{x}_i, \mathbf{z}_i) \\
&= \Phi_2(-\boldsymbol{\beta}_c{}'\mathbf{x}_i, \boldsymbol{\gamma}'\mathbf{z}_i, -\rho_1) \\
\mathrm{P}_{00} &= \mathrm{Prob}(\mathrm{y}_i^1 = 0, \mathrm{q}_i = 0 \,|\, \mathbf{x}_i, \mathbf{z}_i) = \mathrm{Prob}(\mathrm{y}_i^{1*} \leq 0, \mathrm{q}_i^* \leq 0 \,|\, \mathbf{x}_i, \mathbf{z}_i) \\
&= \Phi_2(-\boldsymbol{\beta}_c{}'\mathbf{x}_i, -\boldsymbol{\gamma}'\mathbf{z}_i, \rho_1),
\end{aligned} \tag{4.23}$$

where

$$\Phi_2(\boldsymbol{\beta}_c{}'\mathbf{x}_i, \boldsymbol{\gamma}'\mathbf{z}_i, \rho_1) = \int_{-\infty}^{\boldsymbol{\beta}_c{}'\mathbf{x}_i} \int_{-\infty}^{\boldsymbol{\gamma}'\mathbf{z}_i} \phi_2(s_1, s_2, \rho_1)\, d\, s_1\, d\, s_2 \,.$$

The following likelihood function to be maximised is:

$$L = \prod_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{P}_{11}^{\mathrm{y}_i^1 \mathrm{q}_i} \mathrm{P}_{10}^{\mathrm{y}_i^1 (1\text{-}\mathrm{q}_i)} \mathrm{P}_{01}^{(1-\mathrm{y}_i^1)\mathrm{q}_i} \mathrm{P}_{00}^{(1-\mathrm{y}_i^1)(1\text{-}\mathrm{q}_i)} . \tag{4.24}$$

The endogeneity of public funding can be tested using, e.g., the likelihood ratio test for testing H_0: $\rho_1 = 0$. Under the null hypothesis the model consists of two independent probit models, which can be estimated separately (Greene, 1997). In calculating the test statistic, the restricted log-likelihood is thus the sum of the log-likelihoods for the two independent probit models.

4.3.4 Models to be estimated

To conclude the discussion on the econometric setup, the models to be estimated are shortly presented below. The estimation will start with the two independent probit models for complexity (4.15) and radicalness (4.16) assuming homoscedasticity:

$$\mathrm{y}_i^{1*} = \boldsymbol{\beta}_c'\mathbf{x}_i + \mathrm{e}_i$$
$$\mathrm{y}_i^{2*} = \boldsymbol{\beta}_r'\mathbf{x}_i + \mathrm{v}_i .$$

Vector $\mathbf{x}_i$ is a (23 x 1) vector consisting of the explanatory variables defined in Table 1, excluding the variables *DEMAND* and *HORIZONT* as well as the reference groups of *SYSTEM* and *MACHINE* plus a constant and $\mathrm{e}_i \sim \mathrm{N}(0,1)$ for all i = 1, ..., n, $\mathrm{v}_i \sim \mathrm{N}(0,1)$ for all i = 1, ..., n.[13]

This specification will be modified by allowing the variance of the error terms to differ across observations as presented in (4.17) and (4.18):

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[13] See footnote 8.

$$y_i^{1*} = \boldsymbol{\beta}_c'\mathbf{x}_i + e_i,$$
$$\mathrm{Var}(e_i) = \left[\exp(\boldsymbol{\theta}_c'\mathbf{w}_i^c)\right]^2$$

and

$$y_i^{2*} = \boldsymbol{\beta}_r'\mathbf{x}_i + v_i,$$
$$\mathrm{Var}(v_i) = \left[\exp(\boldsymbol{\theta}_r'\mathbf{w}_i^r)\right]^2,$$

where $\mathbf{w}^c$ and $\mathbf{w}^r$ include some of the k explanatory variables (x_1, x_2, ..., x_k) except the constant. Variables were chosen according to their statistical significance. At this point the assumption of homoscedasticity will be tested using the likelihood-ratio and Lagrange multiplier tests.

Finally the bivariate probit specification is estimated in order to take into account the possible endogeneity of public funding. The bivariate probit models (4.21) and (4.22) were:

$$y_i^{1*} = \boldsymbol{\beta}_c'\mathbf{x}_i + e_i, \qquad y_i^1 = 1 \quad \text{if} \quad y_i^{1*} > 0, \quad 0 \text{ otherwise}$$
$$q_i^* = \boldsymbol{\gamma}'\mathbf{z}_i + u_i, \qquad q_i = 1 \quad \text{if} \quad q_i^* > 0, \quad 0 \text{ otherwise}$$

and

$$y_i^{2*} = \boldsymbol{\beta}_r'\mathbf{x}_i + v_i, \qquad y_i^2 = 1 \quad \text{if} \quad y_i^{2*} > 0, \quad 0 \text{ otherwise}$$
$$q_i^* = \boldsymbol{\gamma}'\mathbf{z}_i + u_i, \qquad q_i = 1 \quad \text{if} \quad q_i^* > 0, \quad 0 \text{ otherwise,}$$

where q^* is the unobservable latent variable underlying a binary variable q, which takes value 1 if the innovation project has got public funding and 0 otherwise, (e_i, u_i) ~$N_2(0, 0, 1, 1, \rho_1)$ and (v_i, u_i) ~$N_2(0, 0, 1, 1, \rho_2)$. Both vectors **x** and **z** consist of explanatory variables presented in Table 1 excluding the variables *DEMAND* and *HORIZONT* as well as the reference groups of *SYSTEM* and *MACHINE* plus a constant; in addition, the variables *PROGRAM* and *SUBSIDY* are omitted. If the assumption of homoscedasticity is rejected in the previous phase, heteroscedasticity will be taken into account in the estimation of the bivariate specification. Similarily the assumption of homoscedasticity will be tested in the model describing public funding (4.20). The assumption of no correlation between the error terms (e, u) and (v, u) is tested using the likelihood-ratio test and the Wald test.

4.4 Estimation and the results

This section presents the estimation results of the econometric models. The three different specifications - homoscedastic, heteroscedastic and bivariate - are compared for both dependent variables of *COMP* and *RADICAL* in sections 4.4.1 and 4.4.2, respectively. All the models were estimated by the maximum likelihood method. Since the models are non-linear functions, an iterative procedure is required for estimating the parameters. The algorithm used was Newton's method for the homoskedastic specifications and the Broyden et al. method for the heteroskedastic and bivariate specifications. As was discussed above, it is the marginal effects, not the parameter estimate itself, which should be looked at.

4.4.1 Models explaining the likelihood of complex innovation

Estimation results for the homoscedastic specification explaining the probability of a complex innovation are presented in Table C.1 in Appendix C. In order to study how the inclusion of new variables affects the estimation results, explanatory variables excluding the control variables (*diversif, size, growth, food, paper, chemical, metal, electro, softa, other*) were added step-by-step.

In general, the statistical significance of the explanatory variables does not change considerably when new variables are added to the model. Also the marginal effects of the statistically significant explanatory variables remain rather stable. One change worth noting concerns the marginal effects of the binary variables describing the product class of the innovation. When the explanatory variables related to the type of development work required (*coretech, method, otherdev*) are added to the model, the marginal effects of several variables related to the product class are somewhat changed.

The negative effect of variables *FOOD, PAPER* and *METAL* on the probability of complex innovation is somewhat diminished. This suggests that the variables describing the type of development work required characterise properties typical of these sectors. In fact, a closer look reveals that the development work related to the development of new production methods is significantly more common in sectors described by the variables *FOOD, PAPER* and *METAL* than in the reference group of MACHINE. The share of innovations related to the development of new production methods is 49 %, 42 % and 36 % in the product groups of food, paper and metal respectively, while in machinery it is only 11 % (the average being 19 %). At the same time, innovations related to the development of new production methods are mainly low complexity innovations (71 % compared to 49 % of innovations related to the development or combination of different components or modules).

In contrast to the variables *FOOD, PAPER* and *METAL,* the marginal effect of the variable *SOFTA* increases when explanatory variables related to the type of development work required are added to the model. This reflects the somewhat different characteristic of the software sector. First of all, the development work included in the class "other types of development" is relatively more common (19% of innovations) in the software sector than in the machinery sector (5%). Secondly, while in general other types of development work (such as productisation of service concepts) are less likely to produce complex innovations, this is not the case in the software sector, where 65 % of innovations based on other types of development are complex innovations. These differences in the software sector may be due to the criteria used in defining the complexity of innovations.

The model presented in the last column of Table C.1 as well as in Table 2 below is the starting point for heteroskedastic specifications and bivariate probit models. According to this homoskedastic specification, the importance of scientific and technological advances (*TECH*) as a source of innovation ideas increases the probability of a complex innovation and likewise the importance of collaboration with universities (*UNIV*) during the innovation process has a positive influence on the probability of a complex innovation. In terms of the development work required, the development of production methods and other types of development work are less likely to result in a complex innovation than the development or combination of different components or modules. Public funding, whether related to technology programmes or not, seems to increase considerably the probability of a complex innovation. The control variables related to the firm, namely the size class of the firm (*SIZE*) and the diversification of the knowledge base of the firm as measured by patenting activity (*DIVERSIF*), are both positively related to the likelihood of a complex innovation.

The environment within which innovations are developed seems to have an effect on the probability of a complex innovation. The growth rate of the related sector over the five years preceding the commercialisation (*GROWTH*) is positively related to the probability of a complex innovation. However, the effect is very small – a one per cent increase in the average growth rate increases the probability by roughly one per cent. The effect of the technological environment described by the product class of the innovation in turn reflects the characteristics of different sectors. Compared to machinery, the sectors consisting of food, beverages and tobacco (*FOOD*), wood, wood products, pulp and paper (*PAPER*) and basic metals and metal products (*METAL*) are less likely to produce complex innovations. In contrast, the sectors consisting of electrotechnical products (*ELECTRO*) and software (*SOFTA*) are more often the producers of complex innovations.

Table 2. Single equation probit specifications for the endogenous variable COMP.

	Homoscedastic error term			**Heteroscedastic error term**		
	Coefficient	*Stand. Error*	*Marginal effect (%)*	*Coefficient*	*Stand. error*	*Marginal effect (%)*
CONSTANT	**-1.368*** **	0,227		**-1.138*** **	0.227	
Idea sources						
COMPTION	0.049	0,052	2.0	0.030	0.042	1.3
TECH	**0.151*** **	0,045	**6.0**	**0.138*** **	0.040	**6.1**
REGLTION	-0.047	0,047	-1.9	**-0.104** **	0.043	**-4.5**
Co-operation						
CUSTOMER	0.008	0,048	0.3	0.021	0.039	0.9
VERTICAL	-0.051	0,052	-2.0	-0.055	0.046	-2.4
UNIV	**0.176*** **	0,054	**7.0**	**0.153*** **	0.048	**6.7**
RCENTRE	0.049	0,057	1.9	-0.016	0.048	0.7
Development work (system)						
CORETECH	-0.053	0,122	-2.1	-0.145	0.112	-6.4
METHOD	**-0.369** **	0,159	**-14.3**	-0.197	0.133	-8.6
OTHERDEV	**0.658*** **	0,221	**-24.1**	**-0.682*** **	0.162	**-27.9**
Public funding						
PROGRAM	**0.470*** **	0,156	**18.6**	**0.659*** **	0.187	**27.8**
SUBSIDY	**0.327** **	0,131	**12.9**	**0.311*** **	0.106	**13.6**
DIVERSIF	**0.013* **	0,007	**0.5**	**0.017** **	0.008	**0.7**
SIZE	**0.218*** **	0,059	**8.7**	**0.168*** **	0,049	**7.4**
GROWTH	**0.028** **	0,013	**1.1**	**0.033** **	0.014	**1.4**
Product class (machine)						
FOOD	**-0.612** **	0,280	**-22.5**	-0.122	0.226	-5.3
PAPER	**-0.447** **	0,237	**-17.0**	**-0.446* **	0.263	**-18.9**
CHEMICAL	0.083	0,186	3.3	0.175	0.138	7.6
METAL	**-0.661*** **	0,204	**-24.4**	**-0.840*** **	0.227	**-33.4**
ELECTRO	**0.554*** **	0,196	**21.8**	**0.576*** **	0.209	**24.4**
SOFTA	**1.150*** **	0,192	**41.6**	**1.209*** **	0.209	**44.7**
OTHER	-0.194	0,193	-7.6	-0.178	0.204	-7.8
Variance function						
OTHERDEV				**-0.924** **	0.367	
PROGRAM				**0.658*** **	0.233	
FOOD				**-1.129** **	0.574	
CHEMICAL				**-1.064*** **	0.308	
LOG-Likelihood	-401			-368		
N	768			768		

		Fitted				Fitted	
		0	1			0	1
Actual	0	322	85	Actual	0	312	95
	1	107	254		1	97	264

In terms of predictive ability, the single equation probit model for complexity seems to work rather well. The model predicts 576 of 768, or 75 per cent, of the observations correctly.[14] Also the likelihood ratio test that all the slope coefficients in the model are zero is strongly rejected.[15]

In order to study the possible presence of heteroscedasticity, Table 2 displays the estimation results of homoskedastic and heteroscedastic specifications. Variables in the variance function were selected according to their statistical significance. Only statistically significant variables were left in the variance function of the final heteroskedastic model, that is, the variables *OTHERDEV, PROGRAM, FOOD* and *CHEMICAL.* Both Lagrange multiplier and likelihood ratio tests clearly reject the null hypothesis of homoscedasticity.[16] In terms of predictive ability, the homoscedastic and the heteroscedastic specifications seem to work equally well. The heteroscedastic specification predicts slightly more ones and fewer zeros but, as a whole, both models predict 75 per cent of observations correctly.

In general, the same explanatory variables are statistically significant both in the homoscedastic and the heteroscedastic specifications. However, there are some differences. The variable *METHOD* loses its statistical significance in the heteroscedastic specification and its effect on the likelihood of a complex innovation is reduced. The same happens with the variable *FOOD*. Meanwhile, the variable *REGLTION* becomes statistically significant in the heteroscedastic specification and its negative impact on the probability increases. Also some marginal effects of the statistically significant variables undergo changes. The effect of the variable *PROGRAM* increases eight per cent from 18 per cent to 26 per cent and the effect of the variable *METAL* decreases from -24 per cent to -32 per cent.

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[14] A threshold value of 0.5 is used. In other words, if the fit given by the regression is larger than 0.5, the observation is classified as 1 and 0 otherwise.
[15] The likelihood ratio test statistic is 259.1, while the critical value with 22 degrees of freedom is 40.3 at the one per cent significance level.
[16] The likelihood ratio test statistic gets a value of 30 and the Lagrange multiplier test statistic a value of 40, while the critical value of Chi-Squared distribution at the one per cent significance level with four degrees of freedom is 13.3.

As explained in section 4.3.3, the explanatory variables describing public funding (*PROGRAM* and *SUBSIDY*) in the single equation specifications may be endogenous. Since public funding is not randomly allocated to different innovation projects, it can be that the selection criteria used in the allocation of funds are such that an innovation project that is likely to result in a specific type of innovation is more likely to get public funding. In such a case, the single equation probit models are likely to overestimate the effect of public funding. In order to study this possible endogeneity, a bivariate probit specification was estimated. As appropriate instruments were not available, the two-equation model was estimated in the spirit of seemingly unrelated regression models. That is, none of the endogenous variables was included in the equations as explanatory variables (see section 4.3.3).

The estimation results for the bivariate specification are presented in Table 3.[17] Both the likelihood ratio and Wald tests reject the null hypothesis that $\rho = 0$ at the 1 per cent level.[18] This provides evidence in favour of joint normality between the error terms from complexity and public funding equations, therefore suggesting that the bivariate probit specification is more appropriate than single equation probit models. However, the marginal effects appear to be rather robust when comparing the single equation heteroscedastic and the bivariate probit specifications. Thereby the endogeneity of public funding does not seem to have a significant impact on the marginal effects of other explanatory variables than the variables *PROGRAM* and *SUBSIDY*.

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[17] No signs of heteroscedasticity were detected in the public funding equation.
[18] The test statistics get the values of 8.7 and 8.4 respectively, compared to the critical value of 6.6 at the one per cent significance level with one degree of freedom.

Table 3. Bivariate probit specification for the endogenous variables COMP and FUNDING.

	Coefficient	*Stand. error*	*Marginal effect for E(COMP/ FUNDING=1) (%)*	*Marginal effect for E(COMP/ FUNDING=0) (%)*
COMP				
CONSTANT	**-0.990*** **	0,222		
Idea sources				
COMPTION	0.034	0,046	1.8	1.8
TECH	**0.158*** **	0,044	**6.3**	**5.8**
REGLTION	**-0.091** **	0,046	**-3.9**	**-3.7**
Co-operation				
CUSTOMER	0.042	0,045	2.1	2.1
VERTICAL	-0.068	0,051	-3.4	3.5
UNIV	**0.213*** **	0,051	**7.5**	**6.4**
RCENTRE	0.079	0,055	2.0	1.4
Development work (system)				
CORETECH	-0.160	0,119	-7.5	-7.4
METHOD	**-0.271* **	0,150	**-11.4**	**-10.5**
OTHERDEV	**-0.696*** **	0,179	**-26.5**	**-22.4**
SIZE	**0.130*** **	0,050	**7.5**	**8.1**
DIVERSIF	**0.022** **	0,008	**0.8**	**0.7**
GROWTH	**0.036** **	0,015	**1.5**	**1.4**
Product class (machine)				
FOOD	-0.112	0,201	-2.9	-2.2
PAPER	**-0.457* **	0,271	**-18.7**	**-16.5**
CHEMICAL	0.148	0,156	6.6	6.6
METAL	**-0.823*** **	0,232	**-32.6**	**-27.7**
ELECTRO	**0.550*** **	0,212	**23.0**	**23.7**
SOFTA	**1.226*** **	0,213	**43.2**	**48.3**
OTHER	-0.175	0,209	-7.7	-7.3
Variance function				
OTHERDEV	**-0.743** **	0,376		
PROGRAM	**0.598*** **	0,220		
FOOD	**-1.352** **	0,611		
CHEMICAL	**-0.653** **	0,291		
FUNDING				
CONSTANT	0.773***	0,214		
Idea sources				
COMPTION	-0.067	0,053		
TECH	0.108**	0,048		
REGLTION	0.002	0,051		
Co-operation				
CUSTOMER	-0.064	0,052		
VERTICAL	0.111*	0,057		
UNIV	0.368***	0,063		

RCENTRE	0.294***	0,065
Development work (system)		
CORETECH	0.151	0,139
METHOD	-0.048	0,168
OTHERDEV	-0.442**	0,217
SIZE	-0.439***	0,059
DIVERSIF	0.024***	0,007
GROWTH	0.015	0,015
Product class (machine)		
FOOD	-0.386	0,266
PAPER	-0.113	0,244
CHEMICAL	-0.065	0,220
METAL	-0.079	0,201
ELECTRO	-0.080	0,219
SOFTA	0.080	0,194
OTHER	0.049	0,224
r	**0.219*****	0,075
LOG-Likelihood	-769	
N	768	

*** = signigicant at one per cent level, ** = significant at five per cent level, * = significant at ten per cent level

In order to get more detailed evidence about the endogeneity of public funding, two two-equation models with the variables *COMP* and *PROGRAM* and the variables *COMP* and *SUBSIDY* as dependent variables were estimated. That is, the second equation of the bivariate probit specification (see section 4.3.3) consisted of modelling the probability of getting public funding related to a technology programme or the probability of getting other types of public funding instead of just modelling the probability of getting public funding in general. The estimation results of these models are presented in Table D.1 in Appendix D. The results indicate that the endogeneity is largely related to the variable *PROGRAM*. Both the Wald test and the likelihood ratio test reject the null hypothesis of $\rho = 0$ at the 1 per cent level when the variable *PROGRAM* is the dependent variable of the second equation but not in the case of the variable

SUBSIDY.[19] This may partly explain the relatively larger marginal effect of the variable *PROGRAM* in the single equation specifications for the variable *COMP*.

All in all, the estimation results of the bivarite probit specifications indicate that public funding - especially in relation to technology programmes - may be endogenous. This would suggest that the bivariate probit specification is more appropriate. However, the marginal effects seem to be rather robust when comparing the bivariate probit specification and the heteroscedastic single equation model. As a result, even though the bivariate specification might be more appropriate, the heteroscedastic single equation model provides accurate enough results and can thus be used as a basis for inference. Only it has to be remembered that especially the marginal effect of the variable *PROGRAM* cannot be interpreted as such.

Going back to the heteroscedastic specification presented in Table 2, it can be noticed that quite many of the original explanatory variables are insignificant in the model. In order to analyse how far the model can be simplified without affecting the results, the insignificant explanatory variables were omitted from the model one by one. First the innovation-specific insignificant variables were omitted according to their statistical significance so that at every step the variable with the smallest t-statistic was omitted. Then the same procedure was applied to the firm and sector-specific insignificant control variables. The only exception to this was that a variable that was part of the variance function was left in the model also as an explanatory variable even if it was statistically insignificant.

The estimation results of these simplified models are presented in Table E.1 in Appendix E. First, it should be noted that the statistical significance of the variables remains very stable when insignificant ones are dropped. All the explanatory variables that are statistically significant in the original model also remain such all along. In addition, none of the insignificant variables becomes significant as variables are dropped.

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[19] The Wald and likelihood ratio test statistics get the values of 6.8 and 7.5 respectively when the variable *PROGRAM* is the other endogenous variable compared to the values of 0.03 and 0 when the variable *SUBSIDY* is the other endogenous variable. The critical value at the one per cent level with one degree of freedom is 6.6.

Figure 12 shows how the impact of the statistically significant qualitative variables changes as insignificant variables are dropped one by one. In order to make the per cents more comparable, in Figure 12 the values for the variables *TECH*, *UNIV*, *REGLTION* and *SIZE* are the marginal effects multiplied by three. As an example, the per cent related to the variable *TECH* in Figure 12 describes how much the fact that new technologies or scientific breakthroughs have been very important to an innovation's development (3) increases the probability of the innovation being complex compared to being an innovation for the development of which new technologies or scientific breakthroughs have not been important at all (0).[20] In other words, the multiplied marginal effect captures the "full" effect of the variable.

As can be seen from Figure 12, the impact of the variables is very robust on different specifications. They are practically the same, irrespective of the model specification. The variables *DIVERSIF* and *GROWTH,* which can take a wider range of values, were not included in Figure 12. The marginal effect of the variable *DIVERSIF* remained at 1.7 per cent in all but one specification, in which it was 1.6 per cent. The marginal effect of the variable *GROWTH* in turn varied between 1.4 and 1.6 per cent.

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[20] For the classification variables taking 4 different values, it was verified that the marginal effects were roughly the same, whether the effect of a one point increase was counted from 0, 1, 2 or 3 (for the variable *SIZE* from 1, 2, 3 or 4).

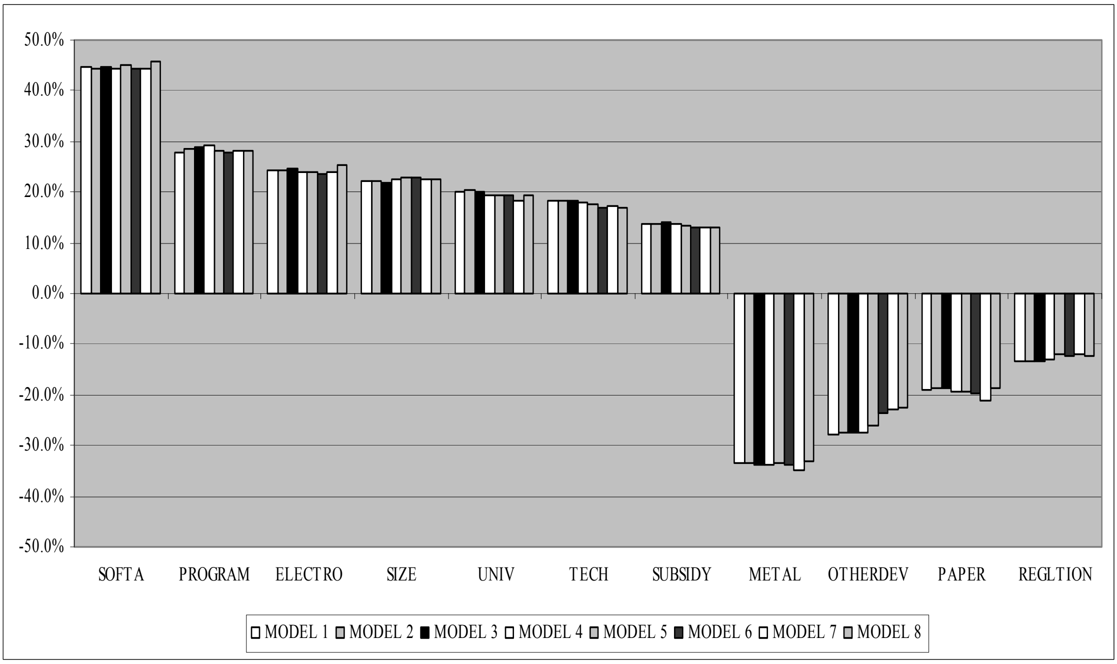

Figure 12. The effect of the statistically significant explanatory variables on the probability of complex innovation [21].

All in all, the results change very little when variables are dropped, which indicates that the model can be simplified substantially by dropping the insignificant variables *RCENTRE*, *CUSTOMER*, *COMPTION*, *VERTICAL*, *CORETECH*, *METHOD* and *OTHER*. Estimation results for the final, simplified model of complexity are presented in Table 4.

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[21] MODEL 1: original model presented in Table 2 - MODEL 2: variable *RCENTRE* dropped - MODEL 3: variable *CUSTOMER* dropped - MODEL 4: variable *COMPTION* dropped - MODEL 5: variable *VERTICAL* dropped - MODEL 6: variable *CORETECH* dropped - MODEL 7: variable *METHOD* dropped - MODEL 8: variable *OTHER* dropped. In the figure the estimated marginal effects of the variables *SIZE, UNIV, TECH* and *REGLTION* have been multiplied by four in order to capture the full effect of those variables (see the text above).

Table 4. Simplified heteroscedastic specification for the endogenous variable COMP.

	Coefficient	*Stand. error*	*Marginal effect (%)*
CONSTANT	**-1.226*** **	0.191	
Idea sources			
TECH	**0.125*** **	0.037	**5.6**
REGLTION	**-0.092** **	0.038	**-4.1**
Co-operation			
UNIV	**0.142*** **	0.046	**6.4**
Development work (system)			
OTHERDEV	**-0.530*** **	0.132	**-22.7**
Public funding			
PROGRAM	**0.652*** **	0.173	**28.2**
SUBSIDY	**0.296*** **	0.100	**13.2**
DIVERSIF	**0.016** **	0.007	**0.7**
SIZE	**0.166*** **	0.046	**7.5**
GROWTH	**0.036** **	0.014	**1.6**
Product class (machine)			
FOOD	-0.134	0.238	-6.0
PAPER	**-0.434* **	0.245	**-18.8**
CHEMICAL	0.186	0.116	8.3
METAL	**-0.815*** **	0.210	**-33.2**
ELECTRO	**0.585*** **	0.201	**25.3**
SOFTA	**1.213*** **	0.192	**45.7**
Variance function			
OTHERDEV	**-1.001*** **	0.359	
PROGRAM	**0.600*** **	0.232	
FOOD	**-1.027** **	0.505	
CHEMICAL	**-1.145*** **	0.309	
LOG-Likelihood	-386		
N	768		

		Fitted	
		0	1
Actual	0	311	95
	1	97	262

4.4.2 Models explaining the likelihood of radical innovation

Estimation results of the single equation probit model explaining the probability of a radical innovation are presented in Table C.2 in Appendix C. The marginal effects of the statistically significant explanatory variables remain stable when new variables are added to the model, which suggests that multi-collinearity does not cause severe problems in the model. The complete model presented in the last column of Table C.2 and in Table 5 below is the starting point for more general specifications. This single equation probit model correctly predicts 67 per cent of the observations. The likelihood ratio test statistic for a test that all the slope coefficients in the model are zero gets a value of 120, which is well above the critical value of 37 at the one per cent significance level.

The variables *TECH* and *UNIV* are both positively related to the likelihood of a radical innovation. This was true also for the complexity of innovation and indicates that connections to the scientific and technological community are important in developing complex and radical innovations. Also according to the homoscedastic specification, the importance of regulation or environmental issues for the development of an innovation seems to increase the probability of a radical innovation. In contrast, innovations that are induced primarily by the threat of competition are more likely to be incremental.

The development work required by an innovation idea that is the most likely to result in a radical innovation is the productisation of a core technology. This conclusion is quite intuitive. The size class of the innovating firm is negatively associated with the development of radical innovations. That is, small firms are more likely to develop radical innovations than larger firms. This may be due to the cumulativeness of innovative activities, meaning that a firm's R&D work builds on its previous innovative activities. Therefore new small firms are more likely to produce radical innovations than large incumbent firms.

The environment within which innovations are developed seems to matter less for the radicalness of innovation than for the complexity. Only the software sector has a statistically significant coefficient. Innovations belonging to the software sector are less likely to be radical. This suggests that a special characteristic of the software sector is the incremental nature of its innovative activities.

Table 5. Single equation probit specifications for the endogenous variable RADICAL.

	Homoscedastic error term			Heteroscedastic error term		
	Coefficient	*Stand. Error*	*Marginal effect (%)*	*Coefficient*	*Stand. error*	*Marginal effect (%)*
CONSTANT	-0.133	0.208		-0.025	0,095	
Idea sources						
COMPTION	**-0.203*** **	0.048	**-8.1**	**-0.067** **	0,026	**-6.0**
TECH	**0.183*** **	0.043	**7.3**	**0.067*** **	0,025	**6.0**
REGLTION	**0.088** **	0.045	**3.5**	0.021	0,016	1.8
Co-operation						
CUSTOMER	-0.012	0.045	-0.5	0.004	0,016	-0.4
VERTICAL	0.025	0.048	1.0	-0.011	0,018	-1.0
UNIV	**0.124** **	0.051	**5.0**	**0.048** **	0,022	**4.3**
RCENTRE	-0.011	0.053	-0.4	-0.010	0,018	-0.8
Development work (system)				0.114*	0,064	10.2
CORETECH	**0.261** **	0.115	10.4	0.114*	0,064	10.2
METHOD	0.119	0.145	4.7	0.106	0,067	9.4
OTHERDEV	0.139	0.191	5.5	0.333	0.129	3.0
Public funding						
PROGRAM	0.140	0.150	5.6	**0.113***	0,061	**10.1**
SUBSIDY	**0.278** **	0.121	11.0	**0.099** **	0,050	**8.8**
DIVERSIF	0.002	0,006	0.07	**0.004***	0,002	**0.4**
SIZE	**-0.140*** **	0.055	-5.6	**-0.068** **	0,027	**-6.1**
GROWTH	-0.005	0.013	-0.2	**-0.011***	0,006	**-1.2**
Product class (machine)						
FOOD	-0.140	0.244	-5.6	-0.065	0,087	-5.7
PAPER	-0.104	0.217	-4.1	-0.038	0,067	-3.4
CHEMICAL	0.103	0.178	4.1	0.015	0,054	1.3
METAL	-0.159	0.185	-6.3	-0.031	0,057	-2.7
ELECTRO	0.178	0.191	7.1	**0.187***	0,106	**16.6**
SOFTA	**-0.402*** **	0.175	**-15.6**	**-0.212** **	0,084	**-18.2**
OTHER	-0.048	0.184	-2.0	-0.042	0,075	-3.7
Variance function						
CORETECH				**-1.079*** **	0,308	
METHOD				**-1.187*** **	0,342	
GROWTH				**-0.089*** **	0,030	
ELECTRO				**1.231** **	0,530	
LOG-Likelihood	-472			-461		
N	768			768		

		Fitted				Fitted	
		0	1			0	1
Actual	0	280	119	Actual	0	291	108
	1	135	234		1	143	226

Table 5 also presents the heteroscedastic specification of the model. For the variance function only the statistically significant variables are reported in the estimation results. Both the Lagrange multiplier and likelihood ratio tests reject the null hypothesis of homoscedasticity at the one per cent significance level, which indicates that the heteroscedastic specification should be preferred over the homoscedastic one.[22] The variance function consists of the variables *OTHERDEV*, *METHOD*, *GROWTH* and *ELECTRO*. The heteroscedastic specification correctly predicts 67 % per cent of the observations as did the homoscedastic one.

In terms of statistical significance and marginal effects, there are some differences between the two specifications. First of all, the variable *REGLTION* loses its statistical significance in the heteroscedastic specification and its marginal effect is halved. On the other hand, the variables *PROGRAM, DIVERSIF, GROWTH* and *ELECTRO* gain statistical significance in the heteroscedastic specification and their effect on the probability of a radical innovation is increased. The variables *PROGRAM, DIVERSIF, GROWTH* and *ELECTRO* have a positive effect on the probability of a radical innovation, but interestingly the variable *GROWTH* has a small negative effect.

Table 6 presents the bivariate probit estimation results. The setup of the bivariate probit specification is the same as it was for the variable *COMP*. In other words, the two equation system consists of a radicalness equation and a public funding equation. Neither of the endogenous variables is included as an explanatory variable in the other equation and the error terms of the equations are assumed to follow a bivariate normal distribution with a correlation coefficient of ρ. The estimation results indicate that there is a small positive correlation between the error terms. However both the Wald and likelihood ratio tests fail to reject the null hypothesis that $\rho = 0$ at the one per cent level.[23]

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[22] The test statistics are 15.1 and 21.6 for the Lagrange multiplier and likelihood ratio tests respectively compared to the critical value of 13.3 at the one per cent level.
[23] The test statistics are 5.7 and 5.9 respectively.

Table 6. Bivariate probit specification for the endogenous variables RADICAL *and* FUNDING.

	Coefficient	*Stand. error*	*Marginal effect for E(RADICAL/ FUNDING=1) (%)*	*Marginal effect for E(RADICAL/ FUNDING=0) (%)*
RADICAL				
CONSTANT	0.038	0,102		
Idea sources				
COMPTION	**-0.075*****	0,029	**-6.3**	**-5.9**
TECH	**0.079*****	0,028	**6.4**	**6.0**
REGLTION	0.026	0,018	2.2	2.1
Co-operation				
CUSTOMER	0.001	0,018	0.3	0.4
VERTICAL	-0.011	0,019	-1.3	-1.4
UNIV	**0.066****	0,026	**4.4**	**3.7**
RCENTRE	0.001	0,019	-0.9	-1.3
Development work (system)				
CORETECH	**0.122***	0,069	**9.9**	**9.5**
METHOD	0.107	0,070	9.3	9.3
OTHERDEV	0.029	0,139	4.1	4.5
SIZE	**-0.087*****	0,031	**-6.0**	**-5.1**
DIVERSIF	**0.005***	0,003	**0.3**	**0.3**
GROWTH	-0.009	0,006	-1.0	-1.0
Product class (machine)				
FOOD	-0.068	0,095	-4.3	-3.7
PAPER	-0.035	0,074	-2.6	-2.3
CHEMICAL	0.020	0,061	2.0	2.1
METAL	-0.035	0,063	-2.7	-2.5
ELECTRO	0.162	0,106	14.1	14.1
SOFTA	**-0.215****	0,087	**-18.2**	**-16.9**
OTHER	-0.030	0,082	-2.7	-2.7
Variance function				
CORETECH	-0.967***	0,305		
METHOD	-1.176***	0,342		
GROWTH	-0.077***	0,029		
ELECTRO	0.935*	0,517		

Table continues…

FUNDING		
CONSTANT	0.787***	0.216
Idea sources		
COMPTION	-0.061	0,054
TECH	0.110**	0,049
REGLTION	-0.003	0,051
Co-operation		
CUSTOMER	-0.065	0,052
VERTICAL	0.109*	0,057
UNIV	0.375***	0,062
RCENTRE	0.292***	0,066
Development work (system)		
CORETECH	0.155	0,140
METHOD	-0.059	0,167
OTHERDEV	-0.455**	0,211
SIZE	-0.443***	0,060
DIVERSIF	0.025***	0,007
GROWTH	0.016	0,016
Product class (machine)		
FOOD	-0.404	0,265
PAPER	-0.123	0,242
CHEMICAL	-0.095	0,213
METAL	-0.077	0,201
ELECTRO	-0.099	0,220
SOFTA	0.062	0,195
OTHER	0.052	0,223
r	**0.164****	0,069
LOG-Likelihood	-842	
N	768	

*** = signigicant at one per cent level,
** = significant at five per cent level,
* = significant at ten per cent level

It seems that the endogeneity of public funding is a minor issue when analysing the radicalness of innovation. This result is confirmed by separate bivariate specifications for the variables *RADICAL* and *PROGRAM* and for the variables *RADICAL* and *SUBSIDY*. In both cases the null hypothesis of $\rho = 0$ cannot be rejected (see Table D.2 in Appendix D). Therefore the heteroscedastic specification will be the one left for final inference.

In order to analyse how much the original heteroscedastic specification can be simplified, the insignificant explanatory variables were dropped from the model one by one in a manner similar to what was done with the complexity model. First the innovation-specific insignificant variables were dropped such that the one with the lowest t-value was omitted at each step. Then the same procedure was applied to the insignificant firm and sector-specific control variables. Only those insignificant variables that were also in the variance function were left in the model. The estimation results of these different specifications are presented in Table E.2 in Appendix E.

As in the complexity models, the statistical significance of the variables remains very stable when insignificant ones are dropped. All the explanatory variables that are statistically significant in the original model also remain such all along. In addition, none of the insignificant variables becomes significant as variables are dropped. In addition to the statistical significance of the variables, also changes in the marginal effects have to be analysed. Notable changes in some marginal effects when a variable is dropped would speak against the omission of that variable.

Figure 13 presents how the impact of the statistically significant classification variables change as insignificant variables are dropped one by one. For the sake of comparability of the values, in the figure the values for the variables *TECH*, *COMPTION, UNIV* and *SIZE* are the marginal effects multiplied by three. Those variables can get four different values, while the other variables presented in Figure 13 are binary. That way the values presented in the figure represent the full effect of those variables. As an example, the impact of *UNIV* in Figure 13 describes how the fact that collaboration with universities or research centres has been very important for an innovation's development (3) increases the probability of the innovation being radical, compared to an innovation for the development of which collaboration with universities has not been important at all (0).[24] In the case of binary variables, the effect is simply the extent to which

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[24] For the classification variables taking four different values, it was verified that the marginal effects were roughly the same whether the effect of a one point increase was counted from 0, 1, 2 or 3 (for the variable *SIZE* from 1, 2, 3 or 4).

the class of a given innovation (e.g., has got funding related to a technology programme) changes the probability of it being radical.

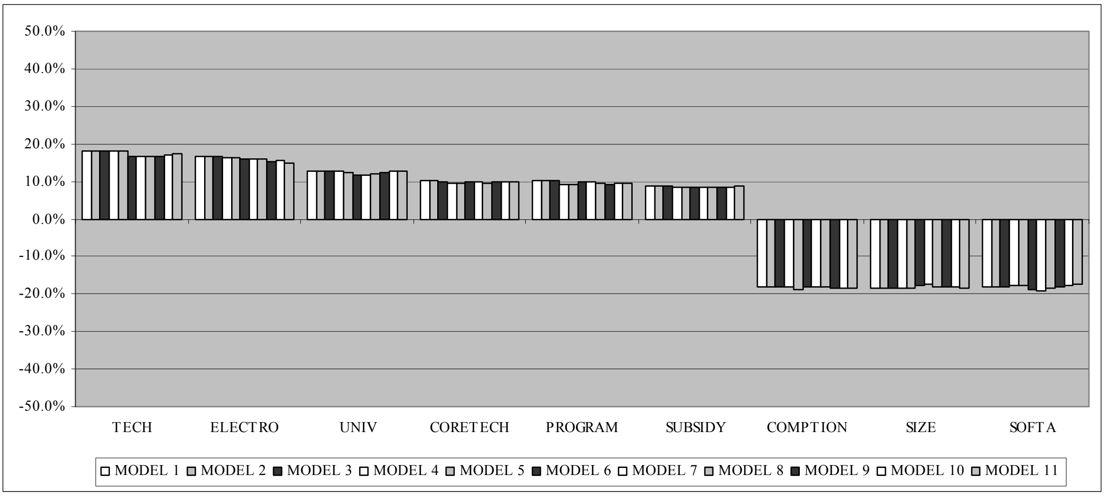

Figure 13. The effect of the statistically significant variables on the probability of radical innovation [25].

The variables *DIVERSIF* and *GROWTH,* which can take a wider range of values, were not included in Figure 13. The marginal effect of the variable *DIVERSIF* remained at 0.4 per cent irrespective of the specification, meaning that an increase in the variable *DIVERSIF* by one unit increases the probability of a radical innovation by 0.4 per cent. The marginal effect of the variable *GROWTH* in turn varied between -1.1 and -1.3 per cent. The marginal effect tells how much a one per cent increase in the variable *GROWTH* changes the probability of a radical innovation.

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[25] MODEL 1: original model presented in table 5 - MODEL 2: variable *CUSTOMER* dropped- MODEL 3: variable *OTHERDEV* dropped - MODEL 4: variable *RCENTRE* dropped - MODEL 5: variable *VERTICAL* dropped - MODEL 6: variable *REGLTION* dropped - MODEL 7: variable *CHEMICAL* dropped - MODEL 8: variable *PAPER* dropped - MODEL 9: variable *OTHER* dropped - MODEL 10: variable *METAL* dropped - MODEL 11: variable *FOOD* dropped. In the figure the estimated marginal effects of the variables *TECH, UNIV COMPTION* and *SIZE* have been multiplied by four in order to capture the full effect of those variables (see the text above).

Figure 13 indicates that despite the omission of variables, the effect of statistically significant variables on the probability remains stable. Clearly the simplifications of the original specification do not cause any notable changes in the original model. As a result, the variables *CUSTOMER*, *OTHERDEV*, *RCENTRE*, *VERTICAL*, *REGLTION*, *CHEMICAL*, *PAPER*, *OTHER*, *METAL* and *FOOD* can be dropped from the heteroscedastic specification. The estimation results of the final model of radicalness is presented in Table 7.

Table 7. Simplified heteroscedastic specification for the endogenous variable RADICAL.

	Coefficient	*Stand. error*	*Marginal effect (%)*
CONSTANT	-0.017	0.081	
Idea sources			
COMPTION	**-0.068*** ***	0.026	**-6.1**
TECH	**0.064*** ***	0.024	**5.8**
Co-operation			
UNIV	**0.047** **	0.021	**4.3**
Development work (system)			
CORETECH	**0.108***	0.057	**6.5**
METHOD	0.085	0.060	4.0
Public funding			
PROGRAM	**0.105***	0.055	**9.5**
SUBSIDY	**0.097** **	0.048	**8.7**
DIVERSIF	**0.004***	0.002	**0.4**
SIZE	**-0.068** **	0.027	**-6.1**
GROWTH	**-0.009***	0.005	**-1.1**
Product class (machine)			
ELECTRO	**0.166***	0.100	**18.7**
SOFTA	**-0.201*** ***	0.077	**-18.1**
Variance function			
CORETECH	**-1.073*** ***	0.318	
METHOD	**-1.197*** ***	0.343	
GROWTH	**-0.091*** ***	0.030	
ELECTRO	**1.207** **	0.527	

LOG-Likelihood	-463
N	768

		Fitted 0	Fitted 1
Actual	0	291	108
	1	147	222

4.4.3 Summing up the estimation results

Before going on to the discussion of the results, it is probably worthwhile to go back to the final simplified heteroscedastic specifications presented in Tables 4 and 7 and synthesise the estimation results of both models.[26] The results indicate that the importance of new technologies and scientific breakthroughs increases the probability of both complex and radical innovations. The importance of new technologies and scientific breakthroughs for the origin of innovations does not come as a surprise, given that the focus in this study is on innovations of varying technological nature in terms of radicalness and complexity.

The marginal effect of the variable *TECH* is around six per cent in both models, meaning that an increase in the importance of new technologies and scientific breakthroughs by one level increases the probability of complex or radical innovation by six per cent. The marginal effects did not seem to change significantly depending on which level the increase is counted. Therefore an innovation for which new technologies and scientific breakthroughs have been very important is roughly 20 per cent more likely to be radical or complex than an innovation for which new technologies and scientific breakthroughs have not been regarded as important.

The importance of competition for the development of innovations is negatively associated with the radicalness of innovation, meaning that innovations originating from competitive pressure are likelier to be incremental. The importance of regulations and environmental issues for the origin of innovation in turn is negatively associated with the complexity of innovation. That is, the more important regulations and environmental issues are for the development of innovations, the less likely the innovation process is to result in a complex innovation.

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[26] In both of the final models it was checked whether some interaction terms would be required. Since it is impossible to check for all possible interactions (interactions between two variables alone produce 190 different interactions), based on intuition, several interactions that seemed reasonable were tested. No statistically significant interactions were, however, found.

In terms of collaborative partners, only the role of universities in the innovation process proved to be different between innovations of different technological nature. The more important the collaboration with universities, the more likely it is for the innovation to be radical or complex. The effect of collaboration with universities seems to be slightly more pronounced on the complexity of innovation. This may reflect the multiple knowledge inputs needed in the development of complex innovations.

The type of development work underlying innovation most likely to result in a radical innovation is the productisation of a core technology. This is a rather intuitive conclusion. The complexity of innovation in turn does not seem to differ greatly depending on the type of the underlying development work. Only innovations resulting from development included here in the class *OTHER* are clearly less likely to be complex. This result may be due to innovations related to the development of service concepts; productisation of service concepts comprises 47 per cent of the class "other types of development".

Innovation processes that have received public funding seem to be more likely to result in complex or radical innovations. Here it should be remembered that the bivariate probit specifications indicated that when analysing the complexity of innovations, public funding and especially public funding related to technology programmes proved to be endogenous. That is, technology programmes seem to be directed towards innovation projects that are more likely to result in complex innovations. Therefore the marginal effect of the heteroscedastic specification overestimates the effect of technology programmes on the complexity of innovation. However, it can be concluded that public funding seems to facilitate the development of radical and complex innovations.

Of the control variables, the diversification index describing the diversification of the innovator’s knowledge base is positively related to the complexity and radicalness of the innovation. Even though the effect is relatively small, this suggests that the multifunctional knowledge base of the firm enhances the firm's capabilities to exploit various technological opportunities. The size of the firm is positively related to the complexity of innovation but negatively related to the radicalness of innovation.

Favourable demand conditions seem to enhance slightly the development of complex innovations. For the radicalness of innovation the situation is, however, the other way around - favourable demand conditions decrease the probability of radical innovation. This may be due to the construction of the demand variable. Probably a five-year period before the commercialisation of innovation is not adequate when analysing the development of radical innovations.

Inter-sector variations in the development of complex innovations seem to be more pronounced than in the development of radical innovations. This may be due to the measure of complexity, which reflects some features of specific sectors. Quite often innovations which are regarded as complex belong to the so called high-tech sectors like electronics, telecommunications, instruments, electrical equipment, chemicals and machinery equipment, while innovations originating from low-tech sectors like petroleum refining, metal products, basic metals and forestry-based sectors are often classified as simple. This is reflected also in the estimation results. Compared to machinery, innovations belonging to the paper and pulp sector or basic metals and metal products are more likely to be simple, while innovations belonging to the broad sector of electronics and software are more likely to be complex. When analysing the radicalness of innovations, there are only two sectors that seem to differ significantly from the reference class of machinery. Innovations belonging to the electronics sector are more likely to be radical, while innovations belonging to software are more likely to be incremental. This reflects the better technological opportunities in the electronics sector and the incremental nature of innovative activities in the software sector.

5. Discussion

The aim of this work was to identify how innovation processes underlying innovations of varying technological nature differ. That is, to try to find some general characteristics of specific types of innovation processes. Quite a lot is known about firms' innovative activities in general based on a stream of empirical studies, but a thorough innovation-level understanding is missing. An innovation-level understanding, however, is an essential part of the issue. The increased importance of continuous creativity and innovation for sustainable competitiveness has highlighted the role of the government in providing adequate support for innovative activity within a nation. However, this adequate support is not necessarily achieved by applying the same general support scheme to all kinds of innovative activities in all different sectors. Rather, it is the case that the policy should be flexible enough to take into account some specific characteristics of different types of innovative activities. This is not possible unless these specific characteristics are known. Moreover, an innovation-level understanding is essential if some technology policy means are directed to facilitate specific types of innovative activity.

This study contributes to this lack of a thorough innovation-level understanding by analysing how the innovation processes underlying radical versus incremental and complex versus simple innovations differ in terms of some key components related to these innovation processes. These key components are related to: the origin of innovation; collaboration during the development process; the role of the public sector; and the broader environment within which the innovation has been developed. A unique innovation-level database collected by the VTT Technology Studies provided the basis for this analysis. What makes the database unique is that, in addition to the literature-based innovation count data, it includes survey data on a group of collected innovations containing rather detailed information about the development processes underlying them. According to the estimation results, some general patterns emerge from the data that differentiate the development processes underlying innovations of varying technological nature.

First of all, the role of scientific breakthroughs and new technologies as a source of original ideas is highlighted in the case of both complex and radical innovations. For the development of complex innovations, the importance of new technologies and scientific breakthroughs suggests that those fields in which technological development has been especially rapid - like electronics, ICT, biochemistry and software - have provided new opportunities for the development of complex innovations.

In the case of radical innovations, the importance of new technologies and scientific breakthroughs reflects the systematic and deliberate character of firms' contemporary R&D activities. Firms that are wanting to stay at the forefront of development have to follow actively what is going on in, and be part of, the scientific and technological community. Radical compared to incremental refers to something completely new and even though new products do sometimes emerge by accident, they are generally the result of active screening of the technological possibilities. This means that more formal inputs from the science-technology system are usually needed. This finding is in line with previous empirical literature. For example, a study commissioned by the US National Science Foundation on radical innovations revealed that recent scientific advances played a critical part during the development stage (Freeman, 1994).

Another interesting result in relation to the origin of innovation was the role of competitive pressure in inducing innovation. Analysis showed that innovations for the development of which competitive pressure had been important, were more likely to be incremental. This suggests that if an innovation is mainly induced by competition, the innovator is likely to be a follower on the technological front. The innovator is following what others are doing in order to keep up with competitors. Innovations for the development of which regulations or environmental issues had been important were more likely to be simple innovations. This reflects the nature of innovations induced by regulations.

The importance of scientific breakthroughs and new technologies for the development of radical or complex innovations was also reflected in the role of universities as collaborative partners during the innovation process. According to the results, the more important universities are regarded as collaborative partners, the more likely it is for the innovation to be complex or radical. In the literature, the role of universities is in general seen as important for innovative activities. However, often the indirect link between science and industry is emphasised--that is, the role of universities as producers of general knowledge and trained manpower (Pavitt, 1993). This study suggests that even though this may be true in general, in the development of radical or complex innovations also the direct role of universities as collaborative partners is important. A British innovation project called Sappho showed that one determinant of success in innovative activity was the ability to make use of external sources of scientific expertise and advice (Rothwell et al., 1974).

It should, however, be mentioned that the role of universities in firms' innovative activities may be more pronounced in Finland than in other countries. According to CIS studies, Finnish firms have significantly more collaboration with universities than other European countries. In addition, the rise of new generic and science-based technologies like information and communication technology may have intensified the link between science and industry (Freeman, 1994). In relation to the complexity of innovation, the role of universities as collaborative partners highlights the diversified knowledge inputs required in the development of complex innovations. Firms are unlikely to be experts in several different fields and therefore require external help in the development process.

In terms of other collaborative partners, there were no significant differences between innovations of different nature. However the important role of customers as collaborative partners was strikingly pronounced in general. This may be due to the fact that this analysis covers only successful innovations, in the sense that all the innovations in the data have gone all the way from the initial idea to the markets. One of the major findings of the Sappho project, which analysed differences between successful and unsuccessful innovations, was that successful innovators were seen to have a much better understanding of user needs (Rothwell et al., 1974).

The question of the type of development work needed in the innovation process turned out to be rather trivial in relation to the issue of interest. This may point to the content of the question, which probably could have been better structured. As such, the question does not seem to provide any interesting insights into the issue of interest; rather it reflects the definitions of complex and radical innovation.

The role of public funding was highlighted both in the case of complex and radical innovations. Public funding related to technology programmes and also other types of public subsidies increased the probability of a complex or a radical innovation. This would suggest that public subsidies for innovative activities do have an important role in facilitating especially the development of radical and complex innovations. The development of this type of innovation is generally characterised by greater uncertainty and higher risks, which is in line with the theoretical arguments supporting government intervention. One important issue that is not known is whether the same innovative activities would have been undertaken in firms if public funding had not been available. That is, whether the public funding has been a substitute for or complementary to private innovation financing.

The results of the bivarite probit specifications showed that the endogeneity of public funding was mainly present in relation to technology programmes and the complexity of the innovations. This means that in technology programmes the public subsidies are directed to the development of complex innovations. When looking at the descriptions of the technology programmes undertaken by the National Technology Agency (Tekes), this result does not seem that surprising. According to Tekes, the technology programmes are aimed at strengthening the competitiveness of industry, promoting research and enhancing co-operation among companies, research organisations and the public sector. Moreover, it is stated that in general Tekes funding is targeted at projects that produce new know-how, bear high technological and commercial risks and on which the impact of Tekes funding is substantial.

Diversification of a firm's knowledge base was found to be positively related to the development of complex or radical innovations even though the effect was rather weak. This is in line with the theoretical arguments that firms with a diversified knowledge base possess more opportunities to exploit technological and scientific knowledge. The effect of the diversified knowledge base was somewhat more pronounced in the case of complexity. This suggests that the complexity taxonomy does indeed capture to some extent the knowledge requirements underlying the innovation process.

The estimation results also suggest that the environment within which the innovation has been developed does have an effect on the type of innovation developed. Favourable economic conditions in the relevant sector as measured by growth increase the probability of complex innovations. This reflects the greater resource requirements related to the development of complex innovations. Complex innovations are likely to be the result of deliberate research activities requiring longer development times, which naturally increases the costs of development work. During periods of favourable economic development it is easier for firms to release resources for this type of innovative activity.

In terms of radicalness, the result was somewhat more surprising. Favourable economic conditions in the sector were negatively related to the development of radical innovations. This may be explained by the construction of the variable describing the economic environment, but there are also other explanations. First of all, the favourable economic conditions can give more room for incremental innovations. Strong demand enables greater product differentiation and firms play with incremental changes to existing products. Weak demand conditions in turn may force firms to try to find something new. In addition, rougher times are often seen as fuelling the renewal of industrial structures. A good example of this is the severe Finnish recession in the beginning of 1990s, which led to considerable changes in the structure of Finnish industry.

The results indicate that also the technological environment within which innovations are developed matters. This reflects the different technological opportunities of sectors. Especially this is reflected in a sector’s ability to produce complex innovations. Usually complex innovations belong to the high-tech sectors in which technological opportunities are richer, meaning that the underlying technologies provide more opportunities for developing complex innovations. One interesting sector-specific result was that innovations originating from the software sector were more likely to be incremental. This may be somewhat surprising, given the status of the software sector among the fastest-growing sectors in Finland, and it highlights the special incremental nature of innovative activities in the software sector compared to other high-tech sectors.

In terms of the size of the innovating firm, the results indicate that larger firms are more often the developers of complex innovations while small firms generate relatively more radical innovations. The role of large firms in developing complex innovations reflects the resource requirements mentioned above, which are needed in the development of complex innovations. Larger firms are more likely to possess a more diversified knowledge base and to perform R&D activities in a more formal setting.

The role of small firms in generating radical innovations in turn indicates that it may be easier for small firms, which are often also relatively new firms, to develop something completely new. Wallmark and McQuenn (1991), for example, note that innovations which are not a direct continuation of a company's existing product range or a logical development of a company's activity often face difficulties in the existing organisations of that company. On the other hand, it may also be the case that smaller firms tend to regard their innovations as radical more easily. If it is question of a newly established small firm, the innovation is by definition new to the firm and probably the firm is not yet familiar enough with global markets in order to correctly assess the novelty of the product in international markets.

Regarding future research in relation to issues tackled in this study, there are several important questions worth noting. First of all, in addition to the technological nature of innovations, it would be important to compare innovations and innovation processes underlying innovations of different economic value. It is often argued that Finnish firms are better at developing new products than at the commercialisation of new products. However, a new product does not have the desired effect unless it is successfully brought to the market and diffused further. A related issue is to analyse which factors lead to a successful innovation by comparing innovation processes underlying successful and unsuccessful innovations. From a technology policy point of view, it is of central importance to be able to understand, which key characteristics might help in preventing the failure of innovative activities. Also the diffusion of innovations is an important topic, since it makes it possible to analyse the effect and commercial significance of an innovation on a national level.

The results of this study also point to the need for greater understanding of the role of public funding in innovative activity. The results suggest that public funding does play an important role in shaping innovative activities within a nation. Therefore it is of central importance to better understand how and through which channels public funding steers innovative activities, i.e., how the allocation mechanism of public funding functions. This is the direction in which I will be moving in my future research.

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Appendix A: Complexity taxonomy

1. low artefactual complexity/low developmental complexity

   Innovation is a single unit.

2. medium artefactual complexity/low developmental complexity

   Innovation is a unit, development is based on knowledge base from one discipline.

   examples: electronic wheel chair, drill

3. medium artefactual complexity/high developmental complexity

   Innovation is a unit, development is based on knowledge base from several disciplines.

   examples: pharmaceuticals, software, generator

4. high artefactual complexity/high developmental complexity

   Innovation is a system consisting of several functional parts, development has required several different disciplines.

   examples: paper machine, mobile phone network, ocean cruiser

Appendix B: Descriptive statistics of the variables

Table B.1. Descriptive statistics of the variables.

	Mean	Standard deviation	Min	Max
Dependent variables				
COMP	0.47	0.50	0	1
RADICAL	0.48	0.50	0	1
Explanatory variables				
Sources of the original innovation idea				
TECH	1.20	1.20	0	3
DEMAND	2.54	0.69	0	3
COMPTION	1.15	1.04	0	3
REGLTION	1.12	1.17	0	3
Type of development work required				
CORETECH	0.35	0.48	0	1
SYSTEM	0.39	0.49	0	1
METHOD	0.19	0.39	0	1
OTHERDEV	0.08	0.27	0	1
External collaboration				
CUSTOMER	1.71	1.14	0	3
UNIV	0.86	1.05	0	3
RCENTRE	0.84	1.04	0	3
VERTICAL	1.00	1.06	0	3
HORIZONT	0.33	0.68	0	3
Public funding				
PROGRAM	0.25	0.43	0	1
SUBSIDY	0.42	0.49	0	1
Knowledge base				
DIVERSIF	4.41	9.52	0	52
Technological environment				
FOOD	0.06	0.23	0	1
PAPER	0.07	0.25	0	1
CHEMICAL	0.11	0.32	0	1
METAL	0.11	0.31	0	1
MACHINE	0.22	0.41	0	1
ELECTRO	0.19	0.39	0	1
SOFTA	0.14	0.35	0	1
OTHER	0.11	0.31	0	1
Demand conditions				
GROWTH	4.96	5.52	-10.07	25.54
Size of the firm				
SIZE	2.27	1.16	1	4

Appendix C: Estimation results of the homoscedastic specifications

Table C.1. Homoscedastic single equation probit specifications for the endogenous variable COMP.

Variable	***Coefficient***	***Stand. error***	***Marginal effect (%)***	***Coefficient***	*Stand. error*	*Marginal effect (%)*	***Coefficient***	*Stand. error*	*Marginal effect (%)*	*Coefficient*	***Stand. error***	***Marginal effect (%)***
CONSTANT	**-1.011*****	0.178		**-1.200*****	0.196		**-1.110*****	0.204		**-1.368*****	0.227	
Idea sources												
COMPTION	0.028	0.050	1.1	0.043	0.050	1.7	0.045	0.051	1.8	0.049	0.052	2.0
TECH	**0.208*****	0.042	**8.3**	**0.167*****	0.044	**6.6**	**0.165*****	0.045	**6.5**	**0.151*****	0.045	**6.0**
REGLTION	-0.021	0.045	-0.8	-0.047	0.005	-1.9	-0.049	0.047	-2.0	-0.047	0.047	-1.9
Co-operation												
CUSTOMER				0.016	0.047	0.6	0.009	0.048	0.4	0.008	0.048	0.3
VERTICAL				-0.026	0.051	-1	-0.043	0.052	-1.7	-0.051	0.052	-2.0
UNIV				**0.205*****	0.051	**8.1**	**0.218*****	0.052	**8.7**	**0.176*****	0.054	**7.0**
RCENTRE				0.080	0.054	3.2	0.090	0.054	3.6	0.049	0.057	1.9
Development work (system)												
CORETECH							-0.036	0.121	-1.4	-0.053	0.122	-2.1
METHOD							**-0.376****	0.158	**-14.6**	**-0.369****	0.159	**-14.3**
OTHERDEV							**-0.666*****	0.219	**-24.4**	**0.658*****	0.221	**-24.1**
Public funding												
PROGRAM										**0.470*****	0.156	**18.6**
SUBSIDY										**0.327****	0.131	**12.9**
DIVERSIF	**0.017****	0.007	**0.7**	**0.016****	0.007	**0.7**	**0.016****	0.007	**0.6**	**0.013***	0.007	**0.5**
SIZE	**0.164*****	0.056	**6.5**	**0.165*****	0.056	**6.6**	**0.166*****	0.057	**6.6**	**0.218*****	0.059	**8.7**
GROWTH	**0.031****	0.013	**1.2**	**0.030****	0.013	**1.2**	**0.031****	0.013	**1.2**	**0.028****	0.013	**1.1**
Product class (machine)												
FOOD	**-0.808*****	0.261	**-28.6**	**-0.780*****	0.268	**-27.7**	**-0.644****	0.278	**-23.5**	**-0.612****	0.280	**-22.5**
PAPER	**-0.540****	0.226	**-20.2**	**-0.541****	0.231	**-20.3**	**-0.446****	0.236	**-16.9**	**-0.447****	0.237	**-17.0**
CHEMICAL	0.049	0.175	2.0	-0.014	0.180	-0.5	0.071	0.184	2.8	0.083	0.186	3.3
METAL	**-0.745*****	0.195	**-27.1**	**-0.738*****	0.198	**-26.8**	**-0.665*****	0.203	**-24.5**	**-0.661*****	0.204	**-24.4**
ELECTRO	**0.558*****	0.191	**21.9**	**0.554*****	0.193	**21.7**	**0.521*****	0.195	**20.5**	**0.554*****	0.196	**21.8**
SOFTA	**1.012*****	0.180	**37.4**	**1.057*****	0.185	**38.8**	**1.160*****	0.190	**41.8**	**1.150*****	0.192	**41.6**
OTHER	-0.240	0.188	-9.4	-0.230	0.190	-9	-0.192	0.192	-7.5	-0.194	0.193	-7.6
LOG-Likelihood	-425			-413			-406			-401		
N	768			768			768			768		

		Fitted 0	Fitted 1		Fitted 0	Fitted 1		Fitted 0	Fitted 1		Fitted 0	Fitted 1
Actual	0	310	97	0	316	91	0	317	90	0	322	85
	1	107	254	1	106	255	1	111	250	1	107	254

Table C.2. Homoscedastic single equation probit specifications for the endogenous variable RADICAL.

Variable	*Coefficient*	*Stand. error*	*Marginal effect (%)*	*Coefficient*	*Stand. error*	*Marginal effect (%)*	*Coefficient*	*Stand. error*	*Marginal effect (%)*	*Coefficient*	*Stand. error*	*Marginal effect (%)*
CONSTANT	0.266	0.165		0.174	0.179		0.069	0.187		-0.133	0.208	
Idea sources												
COMPTION	-0.216***	0.046	-8.6	-0.214***	0.048	-8.5	-0.207***	0.048	-8.3	-0.203***	0.048	-8.1
TECH	0.222***	0.041	8.9	0.199***	0.043	7.9	0.187***	0.043	7.4	0.183***	0.043	7.3
REGLTION	0.096**	0.044	3.8	0.085*	0.044	-3.4	0.086*	0.045	3.4	0.088**	0.045	3.5
Co-operation												
CUSTOMER				-0.008	0.045	-0.3	-0.016	0.045	-0.6	-0.012	0.045	-0.5
VERTICAL				0.014	0.047	0.6	0.031	0.048	1.2	0.025	0.048	1.0
UNIV				0.147***	0.049	5.8	0.141***	0.050	5.6	0.124**	0.051	5.0
RCENTRE				0.008	0.051	0.3	-0.002	0.052	-0.1	-0.011	0.053	-0.4
Development work (system)												
CORETECH							0.272**	0.115	10.8	0.261**	0.115	10.4
METHOD							0.124	0.144	4.9	0.119	0.145	4.7
OTHERDEV							0.122	0.190	4.9	0.139	0.191	5.5
Public funding												
PROGRAM										0.140	0.150	5.6
SUBSIDY										0.278**	0.121	11.0
DIVERSIF	0.003	0.006	0.1	0.004	0.006	0.1	0.003	0.006	0.1	0.002	0.006	0.07
SIZE	-0.166***	0.052	-6.6	-0.171***	0.052	-6.8	-0.170***	0.052	-6.8	-0.140***	0.055	-5.6
GROWTH	-0.006	0.012	-0.2	-0.006	0.012	-0.2	-0.006	0.013	-0.2	-0.005	0.013	-0.2
Product class (machine)												
FOOD	-0.190	0.234	-7.5	-0.153	0.238	-6.1	-0.179	0.242	-7.0	-0.140	0.244	-5.6
PAPER	-0.138	0.211	-5.5	-0.105	0.213	-4.2	-0.118	0.217	-4.7	-0.104	0.217	-4.1
CHEMICAL	0.177	0.173	7.1	0.142	0.185	5.7	0.104	0.178	4.1	0.103	0.178	4.1
METAL	-0.192	0.180	-7.6	-0.166	0.181	-6.5	-0.174	0.185	-6.9	-0.159	0.185	-6.3
ELECTRO	0.195	0.187	7.8	0.187	0.189	7.5	0.181	0.190	7.2	0.178	0.191	7.1
SOFTA	-0.445***	0.169	-17.2	-0.431***	0.172	-16.7	-0.419***	0.174	16.2	-0.402***	0.175	-15.6
OTHER	-0.075	0.181	-3.0	-0.065	0.182	-2.6	-0.052	0.184	-2.1	-0.048	0.184	-2.0
LOG-Likelihood	-482			-477			-474			-472		
N	768			768			768			768		

		Fitted 0	Fitted 1
Actual	0	271	128
	1	140	229

		Fitted 0	Fitted 1
Actual	0	270	129
	1	150	219

		Fitted 0	Fitted 1
Actual	0	278	121
	1	139	230

		Fitted 0	Fitted 1
Actual	0	280	119
	1	135	234

Appendix D: Estimation results of bivariate probit specifications

Table D.1. Bivariate probit specification with variables COMP *and* PROGRAM *or* SUBSIDY *as endogenous variables.*

	Coefficient	*Standard error*		*Coefficient*	*Standard error*
COMP			**COMP**		
CONSTANT	**-0.971*****	0.220	CONSTANT	**-0.994*****	0.220
Idea sources			Idea sources		
COMPTION	0.035	0.045	COMPTION	0.035	0.045
TECH	**0.157*****	0.043	TECH	**0.153*****	0.043
REGLTION	**-0.092****	0.044	REGLTION	**-0.092****	0.044
Co-operation			Co-operation		
CUSTOMER	0.041	0.043	CUSTOMER	0.041	0.043
VERTICAL	-0.061	0.049	VERTICAL	-0.062	0.049
UNIV	**0.209*****	0.050	UNIV	**0.210*****	0.050
RCENTRE	0.079	0.053	RCENTRE	0.072	0.053
Development work (system)			Development work (system)		
CORETECH	-0.154	0.117	CORETECH	-0.140	0.117
METHOD	**-0.240***	0.141	METHOD	**-0.257***	0.141
OTHERDEV	**-0.687*****	0.170	OTHERDEV	**-0.661*****	0.170
SIZE	**0.126****	0.049	SIZE	**0.126****	0.049
DIVERSIF	**0.022*****	0.008	DIVERSIF	**0.022*****	0.008
GROWTH	**0.037*****	0.014	GROWTH	**0.037*****	0.014
Product class (machine)			Product class (machine)		
FOOD	-0.135	0.203	FOOD	-0.103	0.203
PAPER	**-0.460***	0.271	PAPER	**-0.452***	0.271
CHEMICAL	0.136	0.148	CHEMICAL	0.160	0.148
METAL	**-0.860*****	0.230	METAL	**-0.837*****	0.230
ELECTRO	**0.538*****	0.208	ELECTRO	**0.546*****	0.208
SOFTA	**1.207*****	0.210	SOFTA	**1.205*****	0.210
OTHER	-0.182	0.206	OTHER	-0.174	0.206
Variance function			Variance function		
OTHERDEV	**-0.770****	0.388	OTHERDEV	**-0.727****	0.388
PROGRAM	**0.628*****	0.230	PROGRAM	**0.564****	0.230
FOOD	**-1.386****	0.621	FOOD	**-1.337****	0.621
CHEMICAL	**-0.725****	0.282	CHEMICAL	**-0.712****	0.282
PROGRAM			**SUBSIDY**		
CONSTANT	-1.359***	0.231	CONSTANT	0.488***	0.188
Idea sources			Idea sources		
COMPTION	0.004	0.059	COMPTION	-0.042	0.049
TECH	0.104**	0.052	TECH	0.011	0.042
REGLTION	-0.001	0.057	REGLTION	-0.013	0.044
Co-operation			Co-operation		
CUSTOMER	0.079	0.058	CUSTOMER	-0.067	0.045
VERTICAL	-0.022	0.059	VERTICAL	0.064	0.049
UNIV	0.288***	0.059	UNIV	0.048	0.050
RCENTRE	0.358***	0.059	RCENTRE	-0.041	0.051
Development work (system)			Development work (system)		
CORETECH	-0.133	0.140	CORETECH	0.144	0.116
METHOD	-0.060	0.180	METHOD	0.033	0.148
OTHERDEV	-0.020	0.237	OTHERDEV	-0.201	0.206
SIZE	-0.199***	0.064	SIZE	-0.232***	0.054
DIVERSIF	0.023***	0.007	DIVERSIF	0.005	0.006
GROWTH	0.039***	0.014	GROWTH	-0.016	0.012
Product class (machine)			Product class (machine)		
FOOD	-0.162	0.344	FOOD	-0.454*	0.260
PAPER	0.039	0.273	PAPER	-0.155	0.213
CHEMICAL	-0.313	0.216	CHEMICAL	0.142	0.178
METAL	0.077	0.225	METAL	-0.167	0.189
ELECTRO	-0.457**	0.223	ELECTRO	0.167	0.186
SOFTA	0.448**	0.200	SOFTA	-0.326*	0.175
OTHER	0.058	0.221	OTHER	-0.056	0.188
r	**0.209*****	0.081	r	0.014	0.070
N	768		N	768	
LOG-Likelihood	-737		LOG-Likelihood	-887	
LR-statistic	7.5		LR-statistic	0	

Table D.2. Bivariate probit specification with variables RADICAL *and* PROGRAM *or* SUBSIDY *as endogenous variables.*

	Coefficient	*Standard error*		*Coefficient*	*Standard error*
RADICAL			**RADICAL**		
CONSTANT	0.031	0.102	CONSTANT	0.038	0.100
Idea sources			Idea sources		
COMPTION	**-0.075*****	0.029	COMPTION	**-0.073*****	0.028
TECH	**0.079*****	0.027	TECH	**0.076*****	0.027
REGLTION	0.027	0.018	REGLTION	0.025	0.018
Co-operation			Co-operation		
CUSTOMER	0.001	0.018	CUSTOMER	0.002	0.018
VERTICAL	-0.011	0.019	VERTICAL	-0.011	0.019
UNIV	**0.065****	0.026	UNIV	**0.063****	0.025
RCENTRE	0.002	0.019	RCENTRE	0.002	0.019
Development work (system)			Development work (system)		
CORETECH	**0.124***	0.069	CORETECH	**0.116***	0.067
METHOD	0.109	0.070	METHOD	0.101	0.069
OTHERDEV	0.033	0.140	OTHERDEV	0.028	0.137
SIZE	**-0.086*****	0.031	SIZE	**-0.084*****	0.031
DIVERSIF	**0.005***	0.003	DIVERSIF	**0.005***	0.003
GROWTH	-0.008	0.006	GROWTH	-0.008	0.006
Product class (machine)			Product class (machine)		
FOOD	-0.062	0.093	FOOD	-0.067	0.093
PAPER	-0.033	0.073	PAPER	-0.032	0.072
CHEMICAL	0.018	0.061	CHEMICAL	0.017	0.059
METAL	-0.037	0.062	METAL	-0.034	0.060
ELECTRO	0.161	0.105	ELECTRO	0.156	0.100
SOFTA	**-0.214****	0.087	SOFTA	**-0.208****	0.085
OTHER	-0.026	0.082	OTHER	-0.029	0.080
Variance function			Variance function		
CORETECH	**-0.970*****	0.310	CORETECH	**-0.986*****	0.306
METHOD	**-1.198*****	0.350	METHOD	**-1.195*****	0.348
GROWTH	**-0.075*****	0.029	GROWTH	**-0.079*****	0.029
ELECTRO	**0.911***	0.512	COMPTION	**0.926***	0.508
PROGRAM			**SUBSIDY**		
CONSTANT	-1.378***	0.233	CONSTANT	0.497***	0.188
Idea sources			Idea sources		
COMPTION	0.007	0.060	COMPTION	-0.040	0.048
TECH	0.106**	0.052	TECH	0.012	0.042
REGLTION	0.005	0.058	REGLTION	-0.015	0.045
Co-operation			Co-operation		
CUSTOMER	0.072	0.056	CUSTOMER	-0.066	0.046
VERTICAL	-0.017	0.059	VERTICAL	0.061	0.049
UNIV	0.291***	0.058	UNIV	0.050	0.050
RCENTRE	0.355***	0.059	RCENTRE	-0.034	0.052
Development work (system)			Development work (system)		
CORETECH	-0.126	0.141	CORETECH	0.140	0.117
METHOD	-0.085	0.179	METHOD	0.026	0.149
OTHERDEV	-0.030	0.234	OTHERDEV	-0.206	0.202
SIZE	-0.194***	0.064	SIZE	-0.235***	0.054
DIVERSIF	0.022***	0.007	DIVERSIF	0.006	0.006
GROWTH	0.040***	0.015	GROWTH	-0.017	0.012
Product class (machine)			Product class (machine)		
FOOD	-0.136	0.327	FOOD	-0.457*	0.253
PAPER	0.039	0.275	PAPER	-0.154	0.215
CHEMICAL	-0.299	0.216	CHEMICAL	0.134	0.177
METAL	0.087	0.227	METAL	-0.167	0.189
ELECTRO	-0.459**	0.226	ELECTRO	0.167	0.188
SOFTA	0.455**	0.201	SOFTA	-0.326*	0.175
OTHER	0.063	0.221	OTHER	-0.054	0.189
r	-0.020	0.076	r	**0.144****	0.063
N	768		N	768	
LOG-Likelihood	-813		LOG-Likelihood	-957	
LR-statistic	0.1		LR-statistic	5.4	

Appendix E: Simplification of the final models

Table E.1.Estimation results of the simplified models of complexity.

	MODEL 1		MODEL 2		MODEL 3		MODEL 4		MODEL 5		MODEL 6		MODEL 7		MODEL 8	
	Coefficient	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*
CONSTANT	-1.138***	0.227	-1.142***	0.226	-1.114***	0.219	-1.081***	0.210	-1.129***	0.207	-1.177***	0.204	-1.172***	0.201	-1.226***	0.191
Idea sources																
COMPTION	0.030	0.042	0.029	0.042	0.032	0.042	-	-	-	-	-	-	-	-	-	-
TECH	0.138***	0.040	0.139***	0.039	0.137***	0.039	0.137***	0.039	0.132***	0.038	0.127***	0.038	0.127***	0.038	0.125***	0.037
REGLTION	-0.104**	0.043	-0.103**	0.042	-0.103**	0.042	-0.098**	0.041	-0.090**	0.040	-0.092**	0.040	-0.090**	0.037	-0.092**	0.038
Co-operation																
CUSTOMER	0.021	0.039	0.022	0.038	-	-	-	-	-	-	-	-	-	-	-	-
VERTICAL	-0.055	0.046	-0.053	0.045	-0.047	0.044	-0.045	0.044	-	-	-	-	-	-	-	-
UNIV	0.153***	0.048	0.156***	0.048	0.151***	0.047	0.147***	0.047	0.145***	0.047	0.147***	0.047	0.141***	0.046	0.142***	0.046
RCENTRE	-0.016	0.048	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Development work (system)																
CORETECH	-0.145	0.112	-0.140	0.112	-0.125	0.109	-0.127	0.109	-0.114	0.108	-	-	-	-	-	-
METHOD	-0.197	0.133	-0.189	0.132	-0.175	0.129	-0.176	0.130	-0.166	0.128	-0.108	0.115	-	-	-	-
OTHERDEV	-0.682***	0.162	-0.675***	0.160	-0.665***	0.156	-0.664***	0.154	-0.625***	0.153	-0.658***	0.138	-0.534***	0.134	-0.530***	0.132
Public funding																
PROGRAM	0.659***	0.187	0.673***	0.186	0.683***	0.183	0.690***	0.180	0.654***	0.174	0.650***	0.174	0.658***	0.174	0.652***	0.173
SUBSIDY	0.311***	0.106	0.317***	0.105	0.320***	0.104	0.316***	0.103	0.301***	0.102	0.297***	0.102	0.297***	0.100	0.296***	0.100
DIVERSIF	0.017**	0.008	0.017**	0.008	0.017**	0.008	0.017**	0.007	0.017**	0.007	0.017**	0.007	0.016**	0.007	0.016**	0.007
SIZE	0.168***	0.049	0.168***	0.049	0.165***	0.048	0.171***	0.048	0.170***	0.048	0.172***	0.048	0.168***	0.047	0.166***	0.046
GROWTH	0.033**	0.014	0.033**	0.014	0.033**	0.014	0.033**	0.014	0.033**	0.014	0.034**	0.014	0.033**	0.014	0.036**	0.014
Product class (machine)																
FOOD	-0.122	0.226	-0.127	0.232	-0.147	0.240	-0.139	0.251	-0.118	0.234	-0.162	0.246	-0.192	0.244	-0.134	0.238
PAPER	-0.446*	0.263	-0.441*	0.262	-0.440*	0.261	-0.449*	0.260	-0.446*	0.259	-0.457*	0.259	-0.490*	0.253	-0.434*	0.245
CHEMICAL	0.175	0.138	0.178	0.137	0.173	0.135	0.164	0.135	0.160	0.135	0.139	0.132	0.134	0.130	0.186	0.116
METAL	-0.840***	0.227	-0.843***	0.227	-0.845***	0.225	-0.845***	0.225	-0.828***	0.221	-0.839***	0.220	-0.864***	0.219	-0.815***	0.210
ELECTRO	0.576***	0.209	0.575***	0.209	0.576***	0.208	0.559***	0.207	0.551***	0.207	0.547***	0.208	0.554***	0.207	0.585***	0.201
SOFTA	1.209***	0.209	1.202***	0.208	1.204***	0.207	1.186***	0.204	1.191***	0.202	1.178***	0.202	1.170***	0.201	1.213***	0.192
OTHER	-0.178	0.204	-0.175	0.204	-0.176	0.203	-0.184	0.202	-0.177	0.202	-0.178	0.202	-0.190	0.201	-	-
Variance function																
OTHERDEV	-0.924**	0.367	-0.952***	0.365	-0.940***	0.364	-0.957***	0.370	-0.961***	0.350	-0.968***	0.351	-0.956***	0.353	-1.001***	0.359
PROGRAM	0.658***	0.233	0.663***	0.233	0.650***	0.232	0.648***	0.232	0.601***	0.228	0.593***	0.228	0.602***	0.231	0.600***	0.232
FOOD	-1.129**	0.574	-1.090*	0.564	-1.048*	0.544	-1.056*	0.548	-1.096**	0.543	-1.003**	0.500	-1.030**	0.505	-1.027**	0.505
CHEMICAL	-1.064***	0.308	-1.080***	0.306	-1.124***	0.305	-1.125***	0.313	-1.099***	0.300	-1.073***	0.308	-1.143***	0.310	-1.145***	0.309
LOG-Likelihood	-386		-383		-384		-384		-385		-385		-386		-386	
N	768		768		768		768		768		768		768		768	

Table E.2. Estimation results of the simplified models of radicalness.

	MODEL 1		MODEL 2		MODEL 3		MODEL 4		MODEL 5		MODEL 6		MODEL 7		MODEL 8		MODEL 9		MODEL 10		MODEL 11
	Coefficient	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*	*Stand. error*	*Coefficient*
CONSTANT	-0.025	0.095	-0.022	0.095	-0.016	0.091	-0.015	0.092	-0.020	0.091	-0.004	0.089	-0.006	0.085	-0.004	0.085	-0.006	0.082	-0.014	0.080	-0.017
Idea sources																					
COMPTION	-0.067**	0.026	-0.068**	0.026	-0.067**	0.026	-0.068**	0.027	-0.073***	0.027	-0.066**	0.026	-0.066**	0.026	-0.067**	0.026	-0.067**	0.026	-0.066**	0.026	-0.068***
TECH	0.067***	0.025	0.068***	0.025	0.068***	0.025	0.068***	0.025	0.069***	0.025	0.062***	0.024	0.061***	0.024	0.062***	0.024	0.062***	0.024	0.062***	0.024	0.064***
REGLTION	0.021	0.016	0.021	0.016	0.021	0.016	0.021	0.016	0.022	0.017	-	-	-	-	-	-	-	-	-	-	-
Co-operation																					
CUSTOMER	0.004	0.016	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
VERTICAL	-0.011	0.018	-0.011	0.018	-0.011	0.018	-0.012	0.018	-	-	-	-	-	-	-	-	-	-	-	-	-
UNIV	0.048**	0.022	0.049**	0.022	0.049**	0.022	0.049**	0.022	0.047**	0.022	0.043**	0.021	0.043**	0.020	0.045**	0.021	0.046**	0.021	0.046**	0.021	0.047**
RCENTRE	-0.010	0.018	-0.009	0.018	-0.009	0.018	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Development work (system)																					
CORETECH	0.114*	0.064	0.117*	0.064	0.110*	0.058	0.109*	0.059	0.110*	0.058	0.107*	0.056	0.107*	0.056	0.107*	0.056	0.108*	0.057	0.107*	0.056	0.108*
METHOD	0.106	0.067	0.107	0.067	0.101	0.062	0.100	0.062	0.098	0.063	0.097	0.061	0.097	0.061	0.091	0.061	0.091	0.061	0.087	0.060	0.085
OTHERDEV	0.033	0.129	0.033	0.129	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Public funding																					
PROGRAM	0.113*	0.061	0.114*	0.061	0.113*	0.061	0.104*	0.058	0.106*	0.059	0.107*	0.056	0.106*	0.055	0.104*	0.055	0.103*	0.055	0.103*	0.054	0.105*
SUBSIDY	0.099**	0.050	0.099**	0.050	0.098**	0.050	0.096**	0.050	0.098**	0.050	0.095**	0.048	0.094**	0.048	0.095**	0.048	0.093**	0.048	0.094**	0.047	0.097**
DIVERSIF	0.004*	0.002	0.004*	0.002	0.004*	0.002	0.004*	0.002	0.004*	0.002	0.004*	0.002	0.004*	0.002	0.004*	0.002	0.004*	0.002	0.004*	0.002	0.004*
SIZE	-0.068**	0.027	-0.069**	0.027	-0.068**	0.027	-0.069***	0.027	-0.070***	0.027	-0.065**	0.026	-0.064**	0.026	-0.067**	0.026	-0.066**	0.026	-0.065**	0.026	-0.068**
GROWTH	-0.011*	0.006	-0.011*	0.006	-0.011*	0.006	-0.010*	0.006	-0.011*	0.006	-0.011*	0.006	-0.011*	0.006	-0.010*	0.006	-0.010*	0.005	-0.010*	0.005	-0.009*
Product class (machine)																					
FOOD	-0.065	0.087	-0.066	0.087	-0.065	0.087	-0.066	0.088	-0.067	0.091	-0.085	0.089	-0.089	0.085	-0.077	0.084	-0.069	0.082	-0.058	0.078	-
PAPER	-0.038	0.067	-0.038	0.067	-0.038	0.067	-0.041	0.068	-0.044	0.070	-0.034	0.065	-0.038	0.061	-0.036	0.051	-0.031	0.050	-	-	-
CHEMICAL	0.015	0.054	0.015	0.054	0.016	0.054	0.013	0.054	0.012	0.055	0.009	0.050	-	-	-	-	-	-	-	-	-
METAL	-0.031	0.057	-0.032	0.057	-0.031	0.057	-0.031	0.058	-0.034	0.060	-0.040	0.056	-0.043	0.053	-	-	-	-	-	-	-
ELECTRO	0.187*	0.106	0.187*	0.106	0.187*	0.106	0.186*	0.107	0.191*	0.108	0.179*	0.105	0.178*	0.104	0.177*	0.104	0.168*	0.101	0.173*	0.100	0.166*
SOFTA	-0.212**	0.084	-0.213**	0.083	-0.211**	0.083	-0.210**	0.083	-0.212**	0.083	-0.216**	0.084	-0.218***	0.082	-0.214***	0.081	-0.207***	0.079	-0.200***	0.077	-0.201***
OTHER	-0.042	0.075	-0.042	0.075	-0.042	0.075	-0.043	0.076	-0.046	0.079	-0.040	0.073	-0.043	0.070	-0.034	0.068	-	-	-	-	-
Variance function																					
CORETECH	-1.079***	0.308	-1.067***	0.308	-1.067***	0.308	-1.051***	0.306	-1.017***	0.300	-1.212***	0.320	-1.132***	0.323	-1.108***	0.318	-1.107***	0.320	-1.105***	0.321	-1.073***
METHOD	-1.187***	0.342	-1.194***	0.341	-1.195***	0.341	-1.186***	0.338	-1.122***	0.332	-1.129***	0.350	-1.139***	0.352	-1.134***	0.350	-1.153***	0.351	-1.182***	0.348	-1.197***
GROWTH	-0.089***	0.030	-0.088***	0.030	-0.089***	0.030	-0.088***	0.030	-0.089***	0.029	-0.094***	0.031	-0.095***	0.030	-0.094***	0.030	-0.092***	0.030	-0.094***	0.030	-0.091***
ELECTRO	1.231**	0.530	1.223**	0.529	1.230**	0.530	1.213**	0.529	1.205**	0.530	1.299**	0.541	1.316**	0.535	1.284**	0.534	1.234**	0.534	1.254**	0.533	1.207**
LOG-Likelihood	-461		-461		-461		-461		-461		-462		-462		-462		-463		-463		-463
N	768		768		768		768		768		768		768		768		768		768		768

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Title

Empirical analysis of processes underlying various technological innovations

Abstract

The aim of this study was to analyse systematic differences in the processes underlying different types of innovations. Innovations were differentiated according to their technological nature, which was measured by the radicalness and the complexity of the innovations. The innovations studied were divided into radical and incremental and into complex and simple innovations. Probit models were used to analyse how the development processes underlying radical versus incremental or complex versus simple innovations differ. The theoretical framework of the study was provided by the literature on different innovation theories.

The components of the innovation process in focus can be divided into innovation-specific and firm- or sector- specific factors. Innovation-specific factors were related to the origin of the innovation, collaboration during the development work and the role of public subsidies in the innovation process. Firm- and sector-specific factors in turn consisted of the knowledge base of the innovating firm, the size of the firm and the environment in which the innovation was developed.

The starting point for the analysis was a unique innovation database collected by the VTT Technology Studies. The database consists of basic information on some 1600 Finnish innovations commercialised in Finland mainly during the 1980s and 1990s and more detailed survey data on some 800 innovations. The analysis was based on a subgroup of this survey data, consisting of 768 innovations. Patent data and firm-level information were linked to the survey data.

The results indicate the importance of scientific and technological knowledge in developing radical or complex innovations. The importance of scientific breakthroughs and new technologies as well as collaboration with universities and research centres was pronounced in the case of radical or complex innovations. On the other hand, innovations originating mainly from competitive pressure were more likely to be incremental. The role of public subsidies in research and development work was highlighted in the development of radical or complex innovations. The results also suggest that the environment in which innovations are developed has an effect on the type of innovative activity. Technological opportunities differ among sectors, which is reflected especially in the complexity of innovation. Favourable demand conditions in turn enhance the development of complex innovations, while at the same time allowing room for incremental innovations through more extensive product differentiation.

Keywords

innovations, development processes, probit models, technological nature

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Nimeke

Erityyppisten innovaatioiden taustalla olevat kehitysprosessit

Tiivistelmä

Tutkimuksessa tarkasteltiin, miten teknologiselta luonteeltaan erityyppisten innovaatioiden kehittämisprosessit poikkeavat toisistaan. Innovaation teknologista luonnetta kuvattiin kahdesta eri näkökulmasta. Ensinnäkin innovaatiot jaettiin niiden uutusarvon mukaan radikaaleihin ja inkrementaalisiin innovaatioihin. Tämän lisäksi innovaatiot eroteltiin niiden kompleksisuuden mukaan monimutkaisiin ja yksinkertaisiin innovaatioihin. Probit-malleja soveltamalla tutkittiin, minkälaisia systemaattisia eroja on radikaalien innovaatioiden kehittämisprosessissa verrattuna inkrementaalisten innovaatioiden kehittämiseen sekä monimutkaisten innovaatioiden kehittämisprosessissa verrattuna yksinkertaisten innovaatioiden kehittämiseen. Tutkimuksen teoreettisena viitekehyksenä oli eri innovaatioteorioita käsittelevä kirjallisuus.

Tutkimuksessa tarkastellut kehitysprosessiin liittyvät tekijät voidaan jakaa innovaatiokohtaisiin- ja yritys- tai sektorikohtaisiin tekijöihin. Innovaatiokohtaiset tekijät liittyvät siihen, mistä innovaatioidea on alun perin lähtöisin, minkälainen yhteistyö on ollut tärkeää innovaation kehittämiselle sekä minkälainen rooli julkisella rahoituksella on ollut innovaation kehittämisessä. Yritys- ja sektorikohtaiset tekijät puolestaan liittyvät innovaation kehittäneen yrityksen osaamispohjaan, kokoon sekä yrityksen toimintaympäristöön.

Tutkimus perustui VTT Teknologian tutkimuksen keräämään innovaatioaineistoon. Innovaatioaineisto sisältää perustiedot noin 1 600 Suomessa kehitetystä innovaatiosta, jotka on kaupallistettu pääosin 1980- ja 90-luvuilla. Tätä perustietokantaa on täydennetty noin 800 innovaatiota käsittävällä kyselyaineistolla, joka sisältää yksityiskohtaista tietoa kunkin innovaation kehitysprosessista. Tutkimuksessa käytettiin 768 innovaation joukkoa tästä kyselyaineistosta, johon yhdistettiin yrityskohtaisia tietoja.

Tuloksissa nousi esille tiede- ja teknologiayhteisön merkitys, kun kehitetään radikaaleja tai monimutkaisia innovaatioita. Tieteellisten ja teknologisten läpimurtojen merkitys sekä yhteistyö yliopistojen ja korkeakoulujen kanssa korostuivat sekä radikaalien että monimutkaisten innovaatioiden kehittämisessä. Sen sijaan pääosin kilpailullisista paineista syntyneet innovaatiot olivat todennäköisemmin inkrementaalisia. Radikaalien ja monimutkaisten innovaatioiden taustalta erottuivat myös julkiset tuotekehitystuet. Toimintaympäristö, jossa innovaatio on kehitetty, näyttäisi omalta osaltaan vaikuttavan innovaation teknologiseen luonteeseen. Teknologisissa mahdollisuuksissa on sektorikohtaisia eroja, jotka heijastuvat innovaatiotoiminnan luonteeseen - erityisesti innovaatioiden kompleksisuuteen. Sektorin suotuisa taloudellinen kehitys puolestaan näyttäisi edesauttavan monimutkaisten innovaatioiden kehittämistä ja tarjoavan laajemman tuotedifferentiaation kautta tilaa inkrementaalisille innovaatioille.

Avainsanat

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The aim of this study was to analyse systematic differences in the processes underlying different types of innovations. Innovations were differentiated according to their technological nature, which was measured by the radicalness and the complexity of the innovations. The innovations studied were divided into radical and incremental and into complex and simple innovations. Probit models were used to analyse how the development processes underlying radical versus incremental or complex versus simple innovations differ. The theoretical framework of the study was provided by the literature on different innovation theories. The analysis was based on a large innovation survey of Finnish innovations developed during the 1980s and 1990s.

The results indicate the importance of scientific and technological knowledge in developing radical or complex innovations. The importance of scientific breakthroughs and new technologies as well as collaboration with universities and research centres was pronounced in the case of radical or complex innovations. On the other hand, innovations originating mainly from competitive pressure were more likely to be incremental. The role of public subsidies in research and development work was highlighted in the development of radical or complex innovations. The results also suggest that the environment in which innovations are developed has an effect on the type of innovative activity. Technological opportunities differ among sectors, which is reflected especially in the complexity of innovation. Favourable demand conditions in turn enhance the development of complex innovations, while at the same time allowing room for incremental innovations through more extensive product differentiation.

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Empirical analysis of processes underlying various technological innovations

Tanja Tanayama