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VTT, Vuorimiehentie 5, PL 2000, 02044 VTT
puh. vaihde (09) 4561, faksi (09) 456 4374

VTT, Bergsmansvägen 5, PB 2000, 02044 VTT
tel. växel (09) 4561, fax (09) 456 4374

VTT Technical Research Centre of Finland, Vuorimiehentie 5, P.O.Box 2000, FIN–02044 VTT, Finland
phone internat. + 358 9 4561, fax + 358 9 456 4374

VTT Teknologian tutkimus, Tekniikantie 12, PL 1002, 02044 VTT
puh. vaihde (09) 4561, faksi (09) 456 7007

VTT Teknologistudier, Teknikvägen 12, PB 1002, 02044 VTT
tel. växel (09) 4561, fax (09) 456 7007

VTT Technology Studies, Tekniikantie 12, P.O.Box 1002, FIN–02044 VTT, Finland
phone internat. + 358 9 4561, fax + 358 9 456 7007

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Abstract

Successful innovation is typically defined at the firm level where market shares, productivity, or profitability is taken as an indicator of success. Nonetheless, firms are simultaneously involved in many innovation development projects with varying success. This paper defines the success of innovations through the time taken for the innovations to reach commercialisation and the point of break-even, to investigate the relationships between the sources and success of innovations. The paper uses a database of Finnish innovations commercialised during the 1980s and 1990s, and contributes to previous research by covering a range of different types of innovations from various industries, and by applying econometric duration analysis. The results carry implications for the management of innovation and the design of policy from the viewpoint of trade-offs between the timeliness, objective and outcomes of innovation.

Preface

This report relates to a larger research project on Finnish innovations (Sfinno) undertaken at the VTT Technology Studies since 1998, although the roots of the project extend back to the founding of the VTT Technology Studies (then Group for Technology Studies) in 1992. The broader aim of the Sfinno project has been to analyse recent industrial renewal processes in the Finnish industries from the viewpoint of innovations. The Sfinno-project has been financed by the National Technology Agency of Finland (Tekes).

The ambitious aim of the Sfinno project to relate innovations and their development processes to the renewal of Finnish industries raised various questions about how one might measure the success of innovations. Obviously the contribution of innovations to industrial renewal depends on their success, since successful innovations are a prerequisite for the performance of firms. In a previous report related to the Sfinno-project the focus was on the relationships between innovation processes and the performance of firms. In this report I shift the focus from the firm to the level of innovations, by defining success in terms of the time taken for firms to commercialise their innovations and reach the point of break-even.

The contribution of this report is foremost an empirical one. The idea to use duration analysis for modelling the success of innovations arose during my participation in a course on micro-data econometrics at the Stockholm School of Economics during my year as a visiting researcher at the Royal Institute of Technology in Stockholm. Subsequently, one of the lecturers, Professor Almas Heshmati, provided excellent guidance to the empirical part of this report, for which I am most grateful. I am indebted to my fellow researchers for valuable comments received during the presentation of earlier versions of this report at the Chalmers University of Technology, Department of Industrial Dynamics, as well as at internal seminars of the VTT Technology Studies. Naturally, all remaining misconceptions remain mine alone. I also wish to thank Tekes for their financial support.

Christopher Palmberg, Helsinki 12.11. 2002

Contents

1. Introduction

1.1 Background

Successful innovation is a topical issue for firms and policy makers alike. Successful innovation is the cornerstone of competitive advantage, not only in the high-tech industries, but also in the more traditional and maturing industries. Successful innovation is also a prerequisite for technological change, growth and industrial renewal. The determinants of successful innovation are thus of particular relevance, since they should be taken into account in the design of specific policy measures, as well as for the selection of innovation development projects with a higher success rate. The characteristics of successful innovation are also important from an innovation management viewpoint, as firms are confronted with different trade-offs between the different modes and organisation of their innovative activities, the different nature of innovations, and their success.

Empirical research on successful innovation is nonetheless made more difficult by the multidimensionality of the definition of successful innovation. Success is usually defined by commercial criteria at the firm level, where rising market shares, productivity growth, or profitability are taken as indicators of success. Nonetheless, firms are typically multi-product and simultaneously involved in many innovation development projects with varying success rates, whereby firm-level studies miss out the true diversity of innovation within firms (compare with Pavitt 1998). An alternative approach, common especially in the innovation management literature, has thus been to focus on the success of individual development projects, or innovations. In this vast and ever-growing literature successful innovation is defined in different dimensions, ranging from the technical novelty, commercial success, or commercialisation and break-even times of innovations (for extensive overviews of this literature see Montoya-Weiss & Calantone 1994; Cobbenhagen 2000).

Of the former definition of successful innovations, an especially topical issue relates to the speed with which firms manage to commercialise their innovations in the markets, and return positive cash flows through shorter break-even times. The need for speed is often discussed as a competitive advantage in relation to rising R&D costs in combination with shorter product life cycles, increasing competition, market segmentation and globalisation. (Cooper 2001). By shortening commercialisation times, firms may beat competitors and thereby achieve a first mower advantage in terms of market position and proliferation. The rapid return of positive cash flows on development expenditures, through shorter break-even times, likewise enable firms to continuously and persistently innovate in line with rapid developments in the market (Ali et al. 1995; Karlsson & Åhlström 1999). Indeed, several studies suggest that there is a relationship between shorter commercialisation and break-even times, as well as longer-term profitability and growth at the firm level, even though the nature and strength of these relationships are under debate (Niininen & Saarinen 2000, Cooper 2001 and the references therein; for a critical discussion compare to Kerin et al. 1992; Griffin 1993; Cooper & Kleinschmidt 1995; Lambert & Slater 1999).

The definition of successful innovation relates the discussion to various models of innovation which dissect the innovation process into various stages, and propose that the interactions between science & technology -pull versus market-related forces provide the crucial 'windows of opportunity' and related knowledge for successful innovation within firms. (Kline & Rosenberg 1986; Freeman 1994). Moreover, these interactions are shaped by the broader sectoral context in which firms innovate due to sectoral differences in the nature of technologies, markets and competition. (Malerba & Orsenigo 1997; Marsili 2001). Hence, one key question is how different sources of innovations enable firms' to gain first mower advantages and achieve commercial success with their innovations.

1.2 Purpose and structure

In light of the above, the purpose of this paper is to investigate the relationships between the sources and success of innovations across different sectors, and thus explicitly acknowledge for the sectoral diversity in the sources of innovations. Furthermore, the focus of this paper is on two specific dimensions of successful innovation, namely the time taken for innovations to reach the market and break-even. I thereby contribute to the discussion on successful innovation in three novel ways. First, I suggest a relatively narrow but more objective definition of success, using a unique survey data of some 600 innovations developed in

Finnish manufacturing during the 1980s and 1990s (Palmberg et al. 1999). Secondly, I extend previous studies by covering a large number of sectors, as well as by defining different types of sources of innovations that cut across those sectors (compare to Pavitt 1984; Cesaratto & Mangano 1993; Palmberg 2002). Thirdly, I apply econometric duration analysis for the modelling of the commercialisation and break-even durations, and thus enter relatively uncharted waters from a methodological point of view (see van den Berg 2000 for a discussion of different applications of duration analysis).

The uniqueness of the data that I use in this paper stems from the application of the so-called object-approach to innovation measurement (see Kleinknecht et al. 2002 for a comparison of different approaches to innovation measurement). The definition of an innovation was *"a technologically new or significantly enhanced product from the viewpoint of the firm"* that has been commercialised in the market, of which close to 80 percent are new to the global markets (Palmberg et al. 1999, p. 10 & 22). The innovations and innovators have been identified using literature reviews, the annual reports of large firms and expert opinion in preparation for the survey (compare to Townsend et al. 1981; Kleinknecht & Bains 1993; Santarelli & Piergiovanni 1996; for a thorough discussion of the methodology used in identifying the innovations see Palmberg et al. 1999).[1]

The paper is structured as follows. In section 2 I discuss the chain-linked model of innovation as a relevant theoretical and conceptual framework for the empirical part of the paper. Moreover, I selectively review previous relevant studies with the purpose of relating the discussion of successful innovation in the innovation management literature to the chain-linked model. I also identify sources of heterogeneity across different types of innovations that need to be incorporated in the analysis. In section 3, I present the hazard function as a key concept in duration analysis, derive a set of general duration models with different assumptions about the nature of the hazard function, and discuss the

[1] The identification of innovations has not been based on statistical sampling, since the theoretical population of 'all' innovations is unknown - a common problem of the object approach. Instead, the data collection could be described as a designed census with the aim of identifying all possible innovations adhering to the specific definition used. The coverage of the database in terms of industries and firm size groups is nonetheless representative of innovative activity in Finnish industry (Leppälahti 2000; Palmberg et al. 2000; Pentikäinen et al. 2002).

specification and estimation of their empirical counterparts. Section 4 presents descriptive analysis of commercialisation and break-even durations, as well as estimation results. Section 5 synthesises the findings, while section 6 concludes the paper.

2. A theoretical and conceptual framework

2.1 The chain-linked model of innovation

The focus on the commercialisation and break-even times, or durations, of innovation processes requires a conceptualisation of the different stages of innovation that aids operationalisation in the empirical analysis. While several models of innovation have been proposed over the years, the so-called chain-linked model of innovation by Kline & Rosenberg (1986) is sufficiently general and analytical as a point of departure for my purposes (see Rothwell 1994 for a review of different models of innovation). Moreover, this model is well established and frequently referred to in the literature.

The chain-linked model divides the innovation process into five relatively separable stages. During the first stage of innovation, a need in a potential market is identified. The second stage starts with an invention and/or analytical design for a new process or product that is thought to fill that market need. The third stage marks the start of detailed design and testing, or the actual development of the innovation. During the fourth stage, the emerging design is redesigned and eventually enters full-scale production. The final and fifth stage introduces the innovations to the market, initiating marketing and distribution efforts. Another central feature of the model is the identification of five interrelated paths of innovation, describing different sources of innovations and related knowledge inputs throughout the innovation process (Kline & Rosenberg 1986). The model is illustrated in Figure 1 below.

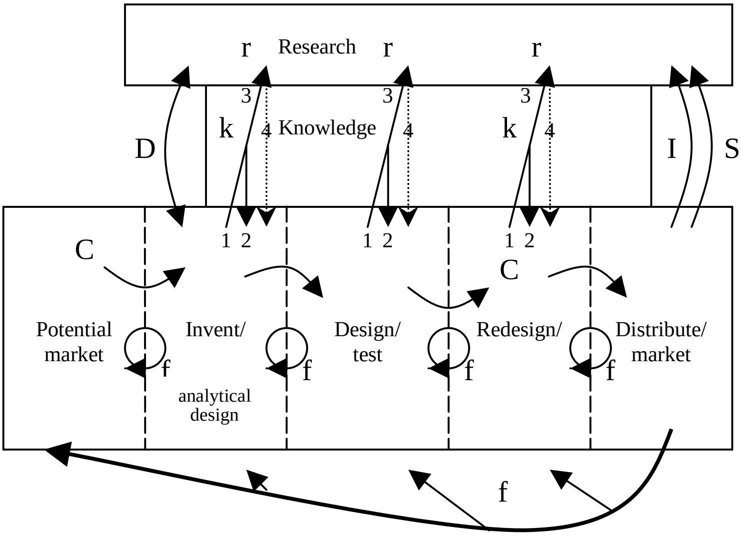

Figure 1. The chain-linked model (slightly adapted from Kline & Rosenberg 1986, p. 290).

Of the five paths of innovation, the first central chain of innovation, is marked with arrows labelled C in the figure. The central chain of innovation generalises innovation processes that emerge from some perception of market needs, where after the invention and/or analytical design is taken through development and production to marketing and distribution, as described above.

The second path of innovation highlights feedback throughout the central chain of innovation. Of these, the most important is the feedback from customers or future users of the innovation, labelled F in the figure. This path highlights users as sources of innovations, or more generally the user-orientation of many innovation processes especially in the instruments, and complex machinery industries (compare to von Hippel 1988; Eliasson 1995). However, the feedback loops arising within the firm, between R&D departments and production, are also covered by this second path and labelled f in the figure. They illustrate continuous in-house problem-solving activity throughout the innovation process, or sources of innovations related to learning by doing and using as discussed in greater depth by Rosenberg (1982).

The third path of innovation links the central chain of innovation to scientific knowledge, defined as *"the creation, discovery, verification, reorganisation, and* *dissemination of knowledge of physical, biological and social nature"* (Kline & Rosenberg 1986, p. 287). This interrelationship between the innovation process and the developments in the sciences is indicated by the arrow labelled D in the figure as the third path of innovation in the model. The point made is that some innovations relate directly to basic and novel research, typically accessed through collaboration with universities or research institutes. This is often the case in the science-based industries, the prime example being the pharmaceutical industry (compare to the science-based sectors in Pavitt 1984).

However, developments in the sciences and basic research is not typically considered the primary source of innovations in other types of industries that rely relatively more on existing knowledge and the modification of available technologies for incremental innovation, especially as mediated through collaboration with suppliers of machinery and equipment from a range of different industries (compare to the specialist-dominated and scale-intensive industries in Pavitt 1984). Thus, the fourth path of innovation, labelled with the arrows K, captures innovation processes feeding, in the first instance, on the pool of existing knowledge (indicated by 1 and 2 in the figure), and only in the second instance on basic novel research if existing knowledge fails to solve problems along the central chain of innovation (indicated by 1 and 3 in the figure). The remaining fifth path of innovation, labelled I in the figure, is less relevant in this context. It is taken to illustrate the opportunities opened up by innovations for the advances in scientific knowledge, as exemplified by the development of faster microprocessors or medical instruments needed to pursue a particular field of basic research.

The merits of the chain-linked model should be viewed in light of previous science & technology -push, versus demand -pull models of innovation that have often been referred to as linear models. The linear models view innovations as arising either purely from developments in the sciences and technologies, or demand from customers and users in the markets (Rothwell 1994). In contrast, the five different paths of innovation identified above cater to the true diversity in the sources of innovations. This also implies that the relative role played by different sources will vary across different types of industries and sectors, as suggested above (compare to Pavitt 1984; Klevorick et al. 1995; Harabi 1995). Nonetheless, as Hall (1994) notes, the chain-linked model can also be criticised for being overly mechanical and ignoring the broader institutional setting wherein innovation processes takes place, leaving no room for regulatory change, standards etc. as the sources of innovations. Neither is the model predictive in the sense that it would suggest how different sources and related knowledge inputs determine the success of innovations. Instead one has to turn to the relevant empirical literature in the field.

2.2 A review of previous research

A first landmark study on successful innovations was by Myers & Marquis in the late 1960s, covering 567 innovations developed in the railroad, computer, and housing industries. The study compared pairs of more and less technologically advanced innovations as a measure of their technological success (referenced in Maidique & Zirger 1984). The next major study was the so-called SAPPHO project undertaken at the Science Policy Research Unit in the UK during the mid 1970s (Rothwell et al. 1974). Again, the methodology was to compare pairs of successful and less successful innovations, this time in the chemicals and instruments industries. A successful innovation was defined as one that attained a significant market penetration and/or made a profit, while an unsuccessful one was associated with the bankruptcy of the commercialising firm, withdrawal of the innovation from the market, or failure of the innovation to reach commercialisation.

Taken together, these two studies defined the subsequent commonly used methodology of identifying discriminating factors differentiating between pairs of successful and less successful innovations. Moreover, they pointed towards five general sources discriminating in favour of successful innovations, namely the involvement of users during innovation, the attention given to marketing and publicity, the efficiency of development in terms of commercialisation times, the effective internalisation of external scientific and technological developments, and managerial competencies. (Maidique & Zirger 1984; Freeman & Soete 1997). Nonetheless, the studies did not incorporate variables capturing the nature of the environment in which the innovations were developed, as these were assumed to be similar across all project due to the focus on particular industries.

Of the pairing studies that followed SAPPHO, the NewProd research project headed by Robert Copper, as well as the Stanford Innovation Project, have been the most ambitious and extensive, covering a range of different industries and countries. In the earlier NewProd studies, successful innovation was again defined in terms of the commercial success of innovations, measured through market sales (Cooper 1979, 1980). In the Stanford Innovation Project the focus was on the US electronics industry, adhering to a similar commercial definition by measuring the degree of deviance of the innovations from financial break-even along an interval scale (Maidique & Zirger 1984). Consequently, these studies identified important success factors mostly related to market-related aspects of innovation, thus essentially confirming the earlier studies. The new variables discriminating between successful and less successful innovations were those capturing the different nature of the innovations, especially the superiority of the innovations from the users viewpoint, the growth of the market and degree of competition, as well as synergies between marketing and R&D activities of the firm commercialising the innovation.

The Stanford Innovation Project is a relevant point of departure here, even though the study is contextually tied to the high-tech electronics industry. One important result of the study was that shorter commercialisation durations clearly distinguished the commercially more successful innovations from others. Maidique & Zirger (1984) also came to the conclusion that previous familiarity with the underlying technologies and markets of the innovation was associated with successful innovations. However, common agreement prevailed that no single factor can be singled out as the key determinant of successful innovation. This was further underlined by follow-up NewProd studies, which established empirically based typologies of successful innovation (Cooper & Kleinschmidt 1987, 1995). These typologies included timeliness (commercialisation times of innovations), commercial (break-even times and sales of innovations), opportunity (opening up of new markets), and market share (acquired market share) dimensions of success. Moreover, Cooper & Kleinschmidt concluded that one dimension of success in fact might conflict with another, depending on the strategies that firms pursue in different markets.

The issue of timeliness, in terms of commercialisation times, and the commercial success in terms of the break-even times of innovations received increasing attention, especially in the 1990s, when time-based management strategies became popular (the primary reference is Clark & Fujimoto 1991). In the meagre but growing empirical literature, the focus has been on the impact of the nature of innovations and entry strategy on commercialisation and break-even durations. Moreover, these studies have highlighted problems related to measuring the timeliness of durations in terms of the closeness of a project in meeting its time goal, which relies on the strong assumption that the goals for project durations were adequately set in the first place (compare to the studies by Maidique & Zirger 1984; Cooper & Kleinschmidt 1995). Instead, they measure commercialisation and break-even durations directly as the length of time in months or years taken for the innovations to reach commercialisation or break-even.

One first identifiable study of relevance to discuss here is Schoonhoven et al. (1990). They touched on the issue of the determinants of commercialisation times by investigating the relationships between different variables on the nature of innovation, and the founding characteristics of new firms in the US semiconductor industry, on the time take to the shipment of their first product. Schoonhoven et al. (1990) also used duration analysis to model these relationships, based on a survey data from 102 firms. They distinguished between innovations achieved through the creation of new knowledge, and those created through the synthesis of existing knowledge familiar to the firm. The founding characteristics of the firms included data on the experience of the staff from the industry in question, the organization and financial resources of the firm, as well as the nature of competition in their respective market niche. The primary results were that innovations synthesising existing knowledge, along with a close relationship between production and marketing within the firm, lower spending on R&D. Moreover, fewer competitors in the market niche shortened the time taken to first shipment.

Firm’s familiarity with the underlying technology was an issue explicitly considered by McDonough & Barczak (1992). They measured the commercialisation times of 32 innovations in 12 firms, defined as the perceived importance of rapid product development according to project leaders at the firms. The familiarity of the underlying technology of the innovations was likewise measured through the perceived familiarity that the R&D staff experienced during the development of the innovations. McDonough & Barczak (1992) also included variables measuring the cognitive problem-solving orientation of the team members. Their results, in fact, contradict those by Schoonoven et al. (1990), even though the authors acknowledge that the sample of firms might have been biased since the focus was on innovation development projects in smaller firms. More significantly, they concluded that the cognitive problem-solving orientation of the R&D staff moderates the relationships between technological familiarity and commercialisation times.

A more recent study, and especially relevant in this context, is Ali et al. (1995). Their primary objective was to explore the relative impact of the nature of innovation, in terms of their novelty to the markets, technological complexity, and different market entry strategies on commercialisation and break-even durations. The data was collected through structured interviews and a survey covering a sample of 73 innovations from small firms in a range of different industries in the US. Ali et al. (1995) used ordinary least square regression, and also included control variables capturing industry- (market growth rate, product substitutability, life span of new technology), firm- (firm size, familiarity with innovation), and project- specific (total development costs, relative price of innovation) sources of heterogeneity. With respect to commercialisation durations, the novelty and complexity of innovations both prolonged the durations (compare also to Griffin 1993). Product advantage as an entry strategy (the innovation perceived as competitive due to it's uniqueness) shortened commercialisation but prolonged break-even durations. Moreover, shorter commercialisation durations, larger firm size and market pioneering (first out on the market with the innovation) were found to be associated with shorter break-even durations. The other control variables did not turn up as significant.

Another relevant study found in the literature is by Karlsson & Åhlström (1999) that elaborates further on the impact of the nature of innovations on commercialisation durations, this time defined as the time taken from the basic idea to full-scale production. Data collection was restricted to cover six firms from various countries in the automobile industry. Different type of innovations are distinguished by various dimensions relating to their functional characteristics, such as car performance, comfort, luxury etc. Using simple correlation analysis, Karlsson & Åhlström (1999) establish a significant relationship between the different dimensions of the nature of innovations and commercialisation durations, measured as a average index for confidentiality reasons. Taken together, as also concluded by Ali et al. (1995) and Karlsson & Åhlström (1999), both of these studies thereby suggest that there is a strategic trade-off between the characteristics of the innovation, and the strive towards reducing commercialisation durations, especially for competitive reasons.

2.3 Definition of successful innovation and sources of heterogeneity

With reference to the discussion above, the definitions of successful innovations used in this paper capture two specific dimensions of successful innovation, amongst many others identifiable in the literature. Both definitions take advantage of the survey that I use, which includes survey questions on the number of years taken for the innovations to reach commercialisation and break-even (the dependent variables are presented and discussed at greater length in section 4.1 below). The first definition is the shortest possible duration for an innovation to reach the market, or commercialisation, from the year of the basic idea of the innovation. In this context, the commercialisation durations allude to the timeliness, or efficiency, of the innovation process along the central chain of innovation. This dimension of successful innovation is thus assumed to capture firm's ability to accelerate innovation processes for achieving first-mower advantages ahead of competitors in a specific market niche. The second definition of a successful innovation is the shortest possible duration for an innovation to reach the point of break-even from the year of commercialisation in terms of generating a positive cash flow. This second dimension thus relates more to the commercial success of the innovation, once it has reached the market and started to accumulate sales. Both definitions of success are thus similar to those used by Ali et al. (1995).

Before proceeding to the methodological discussion and analysis of the results, some considerations on these definitions of successful innovations are warranted. First of all, it should be noted that the innovations identified for the purpose of the survey have passed a threshold criteria of success, in the sense that they are all commercialised in the markets with a high degree of novelty, even though their commercial success varies. This implies that my definitions and measurement of successful innovations are relative ones. They do not distinguish successful innovations from failed ones, but rather distinguish relatively more successful from relative less successful one's by their commercialisation and break-even durations. It should also be stressed that an analytical distinction should be made between success in the shorter and longer run. Hence, an innovation that reaches the market and generates a positive cash flow quickly might offer a temporary advantage to the innovating firm for the reasons discussed above. However, in the longer run, successful innovation will ultimately depend on the sustained competitive position of the innovation in the market, and accumulated sales over a longer period of time.

A second consideration relates to the specific definition used, and their compatibility with the chain-linked model of innovation and previous research. The definition of the commercialisation duration is relatively clear-cut and identical to what Ali et al. (1995) call 'cycle time', as well as Griffin (1993) call 'total time', but slightly different compared to what Karlsson & Åhlström (1999) call 'product development cycle time'. By and large, it thus appears to correspond well to the common understanding of commercialisation times of innovations appearing in the relevant literature. With reference to the chain-linked model, the year of basic idea correspond to the initiation of the second stage of innovation with the introduction of an invention and/or analytical design for an innovation that is thought to fill a specific market need (compare to Kline & Rosenberg (1986)). While this assumption is necessary for the empirical set-up of this paper, it should be stressed that incremental innovation prior to the first invention and/or analytical design is thus assumed away. This might have the potential effect of biasing in favour of shorter commercialisation durations, especially in industries that are characterised by a higher degree of cumulativeness in innovation activity.

The definition of the break-even duration is trickier. In terms of the chain-linked model, the break-even point occurs sometime during the fifth and final stage as the innovation initiates marketing and distribution efforts with the aim of accelerating sales. The year of break-even is here defined as the point in time when the innovation started to generate a positive cash flows. However, given that the durations have been calculated on the basis of a survey, it is uncertain whether the interpretation of break-even for the survey respondent is compatible with the definition used here across all innovations. An alternative interpretation could be that it indicates the point in time when the accumulated positive cash flow exceeds accumulated investment during the development of the innovation, as defined in Ali et al. (1995). However, this interpretation would assume that the survey respondents have the capability to estimate accumulated investments in relation to the accumulated cash flows generated by the innovations - an assumption that I consider less viable. A related consideration to be incorporated in the analysis is the fact that many break-even durations are right-censored since the year of break-even might be out of reach for the survey in the case of the most recently commercialised innovations.

Finally, a third consideration concerns sources of heterogeneity due to the different characteristics of the innovations, which will moderate the effects of different sources of innovations on the durations. With reference to the review of previous research, commercialisation durations appear to be affected by the degree of familiarity of the innovations to the firms, as well as their complexity in terms of the underlying technological knowledge bases (McDonough & Barczak 1992; Ali et al. 1995). Break-even durations appear to be affected by the novelty of innovations to the markets, since novel innovation have a higher probability of achieving first mower advantages irrespective of their commercialisation times. Moreover, Ali et al. (1995) suggest that larger firm size have greater R&D and marketing resources, whereby the size of the commercialising firm is another important sources of heterogeneity across innovations. It also seems clear that both commercialisation and break-even durations should vary from one sector to the next in so far as different sectors reflect the different nature of underlying knowledge bases that firms draw upon, as well as the nature of the markets and competition that the innovations will face (compare to Malerba & Orsenigo 1997; Marsili 2001).

3. Applying duration analysis - modelling hazard functions

3.1 Duration models and the hazard function

Duration analysis is a relatively new econometric technique designed to model the length of spells, or durations, of particular states. The substantive problems that called for the development of such methods related to the biomedical sciences and the modelling of survival times of patients with particular diseases, as well as the engineering sciences in analysis of the breakdown times of machines or components. Thus duration analysis is often also referred to as survival, or lifetime, analysis.

In economics, duration analysis has found most widespread application in the modelling of unemployment durations, where the transition from a state of unemployment to employment is the duration modelled (Allison 1984; Lancaster 1990). Other fields in economics concern the modelling of diffusion times of technologies, firm exit and entry decisions, rate of obsolescence of patents, time to investment, or the survival of new products (van den Berg 2000). Duration analysis also overcomes problems associated with standard regression analysis in cases where the dependent variable is censored, or immeasurable over some range, that is typical to duration data since some durations often are ongoing at the time of data collection.

Adhering to the notation used in Kiefer (1988), the probability distribution of duration can be specified by the distribution function:

(1) $$F(t) = \Pr(T < t)$$

This function specifies the probability that the random variable T, denoting the duration, is less than some time t. The corresponding density function is:

(2) $$f(t) = dF(t)/dt$$

These two functions are equivalent ways of specifying a distribution. A further useful function to define is the survivor function, giving the probability of surviving a duration at least to time t, or that the random variable T will equal or exceed the value t:

(3) $$S(t) = 1 - F(t) = \Pr(T \geq t)$$

From (2) and (3) the hazard function, and the associated hazard rate, can be derived. It gives the probability that the duration ends at time t conditional on the duration having lasted until time t:

(4) $$\lambda(t) = f(t)/S(t)$$

The hazard function can also be expressed more precisely in terms of probabilities as:

(5) $$\lambda(t) = \lim_{h \to 0} \Pr(t \leq T < t + h \mid T \geq t)/h$$

This equation specifies the hazard function in terms of the limit of h, the short interval of length of time after t, as it approaches zero. From above it is easy to realise that the probability distribution function, it's density function, the survivor and hazard functions are related and derivable from each other. While the procedure in standard regression analysis usually relies on specifying the probability distribution functions, the starting point in duration analysis is the specification of the hazard function. This is because duration models are usually cast in terms of conditional rather than unconditional probabilities, acknowledging for the fact that the probability that the hazard rate might also depend on the length of the duration itself. (Kiefer 1988).

Since the hazard rate also depends on the length of the duration itself, duration analysis relies on a range of less common probability distributions and related model parametrisations. The different parametrisations specify how the duration dependency affects the outcome of the estimations. The choice of the parametrisation is tricky in practice, but should reflect theoretical insights applicable to the behaviour of the specific types of duration that is modelled, as well as descriptive analysis of the durations. While the literature identifies a whole range of distributions, the common one's are the exponential, the Weibull, and the logistic distributions (Kiefer 1998; for an extensive overview see Lancaster 1990). In the exponential parametrisation, the hazard rate is modelled as constant over time adhering to an exponential distribution (neutral duration dependency). The Weibull parametrisation relaxes the assumption of a constant hazard rate by allowing it to either increase or decrease over the distribution (positive or negative duration dependency). The logistic parametrisation incorporates durations that exhibit an initially increasing, and thereafter decreasing, hazard rates, or vice versa (combination of increasing and decreasing duration dependency). (Allison 1984).

3.2 Specification and estimation of the empirical models

Since all innovations in the database are commercialised, the probability of commercialisation increases and approaches unity as the innovation process proceeds. Once the innovation is in the market, it should intuitively also be the case that the probability of break-even increases due to accumulated sales and the diffusion of the innovation. A relevant starting point for the specification and estimation of the empirical models is therefore one of positive duration dependency in accordance with the Weibull parametrisation of the hazard function, where the hazard rate of commercialisation or break-even is assumed to increase as time goes by (positive duration dependency). The assumption of constant hazard rates (neutral duration dependency), in accordance with the exponential parametrisation, is clearly too restrictive and unrealistic in this context.

However, it is also possible that the nature of duration dependency might change over ime. In the case of the commercialisation durations, a reversal from increasing to decreasing hazard rates (positive to negative duration dependency) might, for example, relate to a need to resort to basic research to overcome unexpected bottlenecks in the development of innovations (compare to Rosenberg 1982). In the case of the break-even durations, a reversal to decreasing hazard rates might occur in cases where the commercialisation time of an innovation is delayed, the first mower advantage is lost, and there is more room for imitative innovations by competitors which reduces profit margins and successively dampen, or even foreclose, the prospects for achieving a positive cash flow. Taken together, it thus also appears relevant to move beyond the Weibull parametrisations to include logistic parametrisations that incorporates such duration behaviour for the sake of comparison of the underlying assumptions.

Table 1 presents the functional forms of the Weibull and logistic parametrisations, including the density, survival, and hazard functions. The table again adheres to the notation used in Kiefer (1988) for consistency. From the table it is clear that the hazard function of the Weibull parametrisation incorporates both γ and α as unknown parameters. In both the Weibull and logistic parametrisations, α determines the dependency of the duration on time t. In the case of the Weibull parametrisation, there is positive duration dependency if $\alpha > 1$, and negative duration dependency if $\alpha < 1$. In the special case of $\alpha = 1$, the hazard function remains constant over time, and we are back in the exponential parametrisation. In the case of the logistic parametrisation, there is positive duration dependency, turning gradually into negative duration dependency if $\alpha > 1$, while there is negative duration dependency if $0 < \alpha \leq 1$.

Table 1. Functional forms of the Weibull and logistic parametrisations of the duration model.

Distribution	Density function	Survival function	Hazard function
Weibull	$f(t) = \gamma\alpha t^{\alpha-1} \exp(-\gamma t^{\alpha})$	$S(t) = \exp(-\gamma t^{\alpha})$	$\lambda(t) = \gamma\alpha t^{\alpha-1}$
Logistic	$f(t) = \gamma\alpha t^{\alpha-1} / (1 + t^{\alpha}\gamma)^2$	$S(t) = 1/(1 + t^{\alpha}\gamma)$	$\lambda(t) = \gamma\alpha t^{\alpha-1} / (1 + t^{\alpha}\gamma)$

The unknown parameters of the hazard function, including the coefficients of the explanatory variables, are estimated using the method of maximum likelihood (MLE). The method chooses as parameter estimates those values that maximise the likelihood, or probability, of observing the data that have actually been observed. Moreover MLE combines censored and uncensored observations in such a way as to produce estimates that are asymptotically unbiased, normally distributed and efficient. The first step in MLE is to derive the empirical model from the density, survival and hazard functions presented in Table 2 below.

Table 2. The empirical models and likelihood functions of the Weibull and logistic parametrisations of the duration model.

Distribution	Empirical model
Weibull:	$\lambda(t) = \gamma\alpha t^{\alpha-1} = \exp(x'\beta)\alpha t^{\alpha-1}$
Logistic	$\lambda(t) = \gamma\alpha^{\alpha-1} / (1 + t^{\alpha}\gamma) = \exp(x'\beta)\alpha^{\alpha-1} / (1 + t^{\alpha} \exp(x'\beta))$

Leaving the slightly involved maximisation of the log likelihood functions unaccounted for here, the interpretation of the coefficients β of the explanatory variables included in x' require some additional discussion. In the general case, the interpretation of the partial derivatives is similar to linear regression coefficients. Nonetheless, the interpretation of partial effects should be made with due care since they will depend on the duration dependency of the hazard function, that, in turn, might be influence by unobserved heterogeneity despite the inclusion of control variables in the model. Instead the main attention should be given to the sign and significance of the coefficients.

The sign of the coefficient indicates the direction of the effect of the explanatory variable on the conditional probability that the commercialisation or break-even duration ends according to equation (5) above in the hazard rate formulation. A positive sign of the coefficient increases this probability, and shortens the duration, while a negative sign decreases the probability and prolongs the duration. The significance of the coefficients can be tested using standard t-statistics and the associated p-value in the normal fashion. Likewise, the effects of dropped variables on the durations rely on the log likelihood ratio test statistics (LR statistic) commonly used in connection with MLE. The LR statistic is asymptotically Chi-Square distributed with the degrees of freedom equal to the number of restrictions imposed. It is defined as LR = -2 (RLLF - ULLF), where RLLF is the value of the likelihood function of the restricted model and ULLF is the value of the log likelihood of the full, unrestricted, model (Gujarati 1995).

Analysis of model specification, and the fit of the model, boils down to selecting the most appropriate parametrisation of the models. Apart from theoretical insights and descriptive analysis of the durations, a common approach is to use the non-parametric so-called Kaplan-Meier estimates that approximate the shape of the hazard function prior to the inclusion of explanatory variables. The Kaplan-Meier estimates calculate the probability that a duration ends by dividing the number of observations reaching the end of the duration by the number of observations at risk of reaching the end of the durations at a predefine unit in time, when censored observations are also accounted for. Once the explanatory variables are included, residual analysis can be used. In duration analysis the residual is derived by integrating the hazard function as follows, and hence is called the integrated hazard function (Kiefer 1988):

(6) $$\Lambda(t) = \int_0^t \lambda(u)du$$

The integrated hazard function is a kind of a generalised residual, and can be used to compare the fit of different models by their parametrisation in cases where the included explanatory variables are the same. Residual analysis includes analysing descriptive statistics of the residuals for the durations of innovations, t. Table 3 presents the integrated hazard functions of the Weibull and logistic parametrisations of the duration model.

Table 3. The integrated hazard functions of the Weibull and logistic parametrisations of the duration model.

Distribution	Integrated hazard function
Weibull:	$\Lambda(t) = \gamma t^{\alpha}$
Logistic	$\Lambda(t) = \ln(1 + \gamma t^{\alpha})$

3.3 The explanatory variables

The focus of the paper on the relationships between the sources of innovations and the success of innovations takes the empirical analysis into uncharted water, especially from the viewpoint of previous research that has suffered from a lack of data on individual innovations and the sectoral diversity in the sources of innovations. This implies that the choice of substantial explanatory variables has to rely on both the theoretical framework and the related structure of the survey in an explorative manner, while an acknowledgement of potential sources of heterogeneity across the durations of innovations draws on previous research discussed above. My explorative approach also implies that no clear-cut hypothesis concerning the effects of the substantial explanatory variables on the durations can be made. In this sense, the chain-linked model of innovation can only serve as a conceptual organiser for identifying different sources of innovations that presumably should also affect the commercialisation and break-even durations in different ways.

3.3.1 The substantial variables

A large part of the survey was dedicated to tracing the sources of innovations, both in terms of the origin of innovation and the importance assigned to different collaborative partners. The choice of measured variables included in the survey originally reflected the different paths of innovation in the chain-linked model (the theoretical and conceptual points of departure for the survey are discussed in depth in Palmberg et al. 1999). With reference to the chain-linked model, the first path along the central chain of innovation should be interpreted as a general description of innovation processes, whereas the remaining three paths introduce the different sources of innovations of concern here. The following set of explanatory variables is included in both models to capture the nature of these different innovation opportunities. The variables have been reduced from the larger selection of variables using principal component analysis (PCA), as a means to avoid collinearity between the original set of variables, and are thus orthogonal to each other (see appendix 2 for the results of the PCA; Palmberg 2002 for a discussion of the PCA).

Variable	Description [2]
CUSDEM	Highest value of variables customer demand or market niche as sources of innovations
UNIVRES	Highest value of variables collaboration with universities or research organisations as sources of innovations
SCITECH	Highest value of variables scientific breakthroughs or new technologies as sources of innovations
CONSUP	Highest value of variables collaboration with consultancies or suppliers as sources of innovations
REGLEG	Highest value of variables regulations and standards or related environmental issues as sources of innovations
COMPET	Highest value of variables intensification of price competition or rival innovations as sources of innovations

Of these variables, CUSDEM relates to the second path of innovation in the chain-linked model, which suggests that customers as future users open up opportunities to innovate by providing ideas and feedback throughout the innovation process (compare to the arrows labelled F in the chain-linked model in figure 1 above). While the role of customers is acknowledged as an important source of innovations across a whole range of sectors, the seminal study by von Hippel (1988) suggests that customers as users might matter most in cases where innovations are complex and directed towards advanced lead-users in specialised sectors such as medical instruments. This observation is also supported by Eliasson (1995) who finds that advanced customers in the Swedish aeronautics industry have played an important role for innovation and in the transformation of the industry. Subsequently Eliasson & Eliasson (1996) coin the concept of competence bloc to highlight the role of the customer in the selection of successful innovations (compare also to Palmberg 2002a for the case of the Finnish telecom industry).

[2] All variables are measured on a likert scale denoting their degree of importance for the initiation of the innovation process (0 = not important, 1 = minor importance, 2 = important, 3 = very important)

The variable UNIVRES relates to the third path of innovation, which highlights sources of innovations related to developments in the sciences, assimilated through collaboration with universities or research organisations. This variable captures innovations that have their origin in basic or applied novel research in cases where the pool of existing knowledge is insufficient for the development of innovations (compare to the arrow labelled D in the chain-linked model in Figure 1 above). The reliance on novel basic or applied research during innovation is particularly common in science-based sectors, the prime example being the pharmaceuticals and chemicals sectors (Pavitt 1984; Gambardella 1995). Science-based sectors are also typically characterised by higher technological opportunities and R&D-intensity due to higher productivity of R&D in these sectors. Nonetheless, lower R&D-intensities might also conceal science-based innovations, suggesting that innovations drawing on collaboration with universities and research institutes are common in other sectors as well (Palmberg 2002b).

The variable SCITECH relates to the fourth path of innovation, which highlights sources of innovations relating to scientific breakthrough and new technologies external to the firm, which add to the general pool of knowledge underlying innovations (compare to the arrows labelled k in the chain-linked model in Figure 1 above). This variable is thus distinctly different compare to UNIVRES, since innovations draw on the general available pool of knowledge in the first instance, rather than directly on novel basic or applied research. Nonetheless, there appears to be two viable means of assimilating this type of generally available knowledge. Firms might become engaged in their own in-house R&D to develop what Cohen & Levinthal (1990) coin as absorptive capability to absorb external knowledge. Alternatively, firms might dip into the general pool of knowledge through collaboration with a range of external partners.

The variable CONSUP summarises innovation processes drawing on collaboration with consultancies and suppliers as carriers of the available pool of knowledge. I assume that these collaboration with these types of partners point towards frequent spillovers and generic knowledge bases, which induce firms to seek complementarities between in-house R&D and external transmitters of such knowledge. The role of consultancies, especially so-called 'knowledge-intensive business services' (KIBS), are especially important in this context (Leiponen 2001). The role of suppliers as sources of innovations through supplying machinery and equipment is also well documented, especially in supplier-dominated sectors where firms a less dedicated to in-house R&D (Pavitt 1984). Taken together, the variable CONSUP can thus also be related to the fourth path of the chain-linked model.

The inclusion of the two remaining variables REGLEG and COMPET is motivated more by the structure of the survey, and it's ambition to cover the true diversity in the sources of innovations, rather than to the chain-linked model as such. The first of these, REGLEG relates to the broader issue of the regulatory change and environmental issues in connection with innovation. It captures regulatory change and standardisation, especially related to environmental issues, that might contribute in various ways to innovation by enforcing interfaces between previously disconnected technologies, and by opening up new markets (the construction, telecom, or pharmaceuticals industries are prime examples). The variable COMPET captures innovation processes induced by a competitive environment in sectors characterised by price competition and rival innovation, assumed to be related to the saturation of markets and the maturing of sectors (compare to the product or industry life cycle discussion in Utterback 1994).

3.3.2 Controlling for sources of heterogeneity

The issue of heterogeneity in a duration analysis set-up is important, as was hinted above, because unobserved/unaccounted heterogeneity biases in favour of decreasing duration dependence, which might blur interpretations and make interference more unreliable. The most obvious way to control for heterogeneity is to include the sources of such heterogeneity as explanatory dummy variables. The following dummy variables are thus included in the two models to cater to different sources of heterogeneity, listed first for the modelling of commercialisation durations, and thereafter for the modelling of break-even durations:[3]

Variable	Description
FNOVEL	Value 1 if innovation is entirely new to the firm and 0 if innovation is a major or minor improvement to existing products
COMPLEX	Value 1 if innovation is of the high-complexity type and 0 if innovation is of the low-complexity type

The dummy variable FNOVEL captures the technological familiarity of the innovation to the firm in terms of how much the firm has had to extend it's knowledge base. The dummy variable COMPLEX captures the degree of complexity of the innovation by the degree to which it involves the combination of different technologies and related components (a telephone switching system would be an example of a high complexity innovation, while a new type of glue-laminated timber would be an example of a low-complexity innovation). Together these two variables are assumed to control for the different nature of innovations that McDonough & Barczak (1992), Ali et al. (1995), and Karlsson & Åhlström (1999) proposes as major sources of heterogeneity in terms of commercialisation durations. Here the assumption of their effects on commercialisation durations is also the same, namely that innovations of greater novelty to the firm, and of higher complexity, should prolong the durations.

Variable	Description
MNOVEL	Value 1 if innovation is new to the global markets and 0 if innovation is a new merely to the Finnish markets
EXPORT	Value 1 if innovation has been exported and 0 if innovation has not been exported
PATENT	Value 1 if the innovation has been patented in Finland or abroad prior to commercialisation and 0 if not patented

[3] A variable to capture innovations involving the development of process technology was included in the original models on commercialisation and break-even durations, but was subsequently dropped due to the insignificance of the related coefficients throughout.

Turning to the dummy variables included to control for the different sources of heterogeneity for the modelling of break-even durations, the attention in the degree of novelty of innovations shifts from the firm to the market viewpoint through the inclusion of the dummy variable MNOVEL, rather than FNOVEL. This is because innovations offering new characteristics to consumers globally rather than domestically should sell better and shorten break-even durations irrespective of the sources of innovations. Moreover, the specification of the model for break-even durations requires the inclusion of the dummy variable EXPORT to control for innovations that are exported and thus probably face a larger market that should enhance the diffusion of the innovation, increase sales and hence shorten break-even durations. The effects of EXPORT on break-even durations could nonetheless be the opposite since the commercialisation of innovations on the global markets probably also require greater marketing and logistic efforts that might prolong break-even durations.

In addition, I include the dummy variable PATENT to capture innovations that have been patented prior to their commercialisation. In this context, I assume that the variable PATENT is distinct from MNOVEL in capturing property rights acquiring to the firm as the innovator, compared to their perceived novelty from the viewpoint of the consumers on the market. A patented innovation might act as a deterrent, block the entry of rival imitative innovations and secure the achievement of temporary monopoly profits, despite first mower advantages, and thus shorten break-even durations. However, a patented innovation has probably also required more development effort due to the complexity and novelty of the underlying technology, which might prolong break-even durations. Moreover, PATENT controls for innovations in product fields and sectors where patent protection is viable in the first place, since it is well known that the propensity to patent depends on firm- and sector- specific issues (Patel 2000).

As has become evident, all the variables discussed above control for different sources of heterogeneity due to the different characteristics of innovations, depending also on whether the focus is on commercialisation or break-even durations. All remaining variables control for the characteristics of the firm and the origin of the innovations by the sector of the commercialising firm, and are included in both models on the commercialisation and break-even durations.

Variable	Description
FSIZE1	Value 1 if the size of the firm commercialising the innovation is 1–9 employees and 0 otherwise
FSIZE2	Value 1 if the size of firm commercialising the innovation is 10–999 employees and 0 otherwise
FISZE3	Value 1 if the size of firm commercialising the innovation is over 1000 employees and 0 otherwise

The dummy variables FSIZE1--FSIZE3 control for the size of the firm commercialising the innovation according to the number of employees.[4] FSIZE1 controls for small firms, the share of which is relatively large in the data (compare to Palmberg et al. 1999), while FSIZE3 controls for large firms. The largest firm size group by the number of innovations, FSIZE2, is used as the benchmark. The underlying assumption of including these variables as sources of heterogeneity is to control for larger firms having greater degree of freedom in their innovation strategies due to larger financial resources compared to smaller firms (Ali et al. 1995). Large firms might have both resources and incentives to prolong or shorten commercialisation durations for purely strategic reasons compared to smaller firms, for example in response to developments in demand on the relevant product niche. Likewise they assumedly have greater marketing resources, which should shorten the break-even durations.

Apart from firm size, the nature of different sectors should constitute evident sources of heterogeneity across the durations as suggested above. The assumption here is that different sectors differ in the characteristics of the knowledge base that firms draw upon during innovation, which should have an effect especially on the commercialisation durations. They also differ by the nature of markets and competition, which should be more relevant in the case of the break-even durations. One way to give more analytical content to the assumed effects of different sectors on the durations is to acknowledge the fact that sectors also differ in their R&D-intensities, as indicators of differing levels

[4] The defined firm size groups depart from standard one's applied within the EU since the prime aim was to divide the number of innovations into comparably large firm size groups.

in technological opportunities, or the vitality of developments in the underlying sciences and technologies that firms draw upon (Klevorick et al. 1995). Hence, the sectoral dummies below are roughly ranked by their R&D-intensities. Sectors spending more than 2 percent of total turnover on R&D are classified as high R&D-intensive industries, while those spending less than 2 percent are classified as low R&D-intensive industries (Hatzichronoglou 1997; Statistics Finland 2001).[5]

Variable	Description
High R&D-intensive industries	
ELECTRO	Value 1 if firm commercialising the innovation is classified in the electronics sector and 0 otherwise
CHEM	Value 1 if firm commercialising the innovation is classified in the chemicals sector and 0 otherwise
INST	Value 1 if firm commercialising the innovation is classified in the instruments sector and 0 otherwise
MACH	Value 1 if firm commercialising the innovation is classified in the machinery sector and 0 otherwise
Low R&D-intensive industries	
METAL	Value 1 if firm commercialising the innovation is classified in the metal sector and 0 otherwise
FOOD	Value 1 if firm commercialising the innovation is classified in the foodstuffs sector and 0 otherwise
FOREST	Value 1 if firm commercialising the innovation is classified in the forestry-based sector and 0 otherwise
OTHER	Value 1 if firm commercialising the innovation is classified in other manufacturing sectors and 0 otherwise

[5] Several different variables capturing average growth rates and R&D-intensities across sectors and product groups at the year of commercialisation were included in the original models on commercialisation and break-even durations, but were subsequently dropped due to the insignificance of the related coefficients throughout.

In this set-up, the variables ELECTRO--MACH control for sources of heterogeneity due to innovations originating in the high R&D-intensive industries. Assumedly, commercialisation durations should be longer for innovations originating in these sectors, due to a greater need to become engaged in systematic R&D and lengthier projects to assimilate different sources of innovations. Evident examples are the pharmaceuticals and electronics sectors, in which R&D-intensities tend to be the highest. Alternatively, the variables METAL--OTHER control for sources of heterogeneity due to innovations originating in the low R&D-intensive industries in which commercialisation durations might be shorter. This is due to the different, often incremental, nature of innovation and lesser incentives to become engaged in R&D. The variable MACH, with the greatest number of observations, is used as the benchmark in the estimations.

4. Descriptive and estimation results

4.1 The dependent variables and sources of heterogeneity

The survey data on the duration of commercialisation and profitability times suffers from unit non-response. Due to cases where both the year of basic idea and commercialisation is missing, the number of commercialisation durations reduces from 598 to 521. Due to left-censored durations, in cases where the year of the basic idea is unknown, the number of commercialisation durations reduces from 521 to 489 in descriptive analysis of the data (1 outlier was removed from the sample). The number of break-even durations reduces to 511 due to cases where both the year of commercialisation and break-even is missing, and further to 344 due to right-censored variables in cases where the year of break-even is beyond the coverage of the survey (1 outlier was likewise removed). Since censored observations can be incorporated in the formulation of the log-likelihood functions and MLE, these will not have to be omitted in the estimations. However, the censored variables have to be omitted from the subsequent descriptive analysis of the durations.

Turning to the descriptive analysis of the durations, the mean average commercialisation duration is 3.5 years, while the mean break-even duration is 2.3 years. The durations appear surprisingly short, especially in the case of the break-even durations. By the same token it should be added than an assessment of whether these durations are exceptionally short or not is made difficult by the fact that I have not found any other comparable studies, combining a similar kind of data and definitions of the durations as I do in this paper. The only exception is the above referenced study by Ali et al. (1995), who find mean commercialisation durations of 1.55 years, and mean break-even durations of 1.45 years, respectively, which seem to be roughly in line with the results here although both means are lower. One reason for the lower means in their study might be that they only included a sample of firms with less than 100 employees from different manufacturing sectors. They also used a looser definition of the novelty aspects of an innovation.

Another important result is the positive and highly significant correlation between commercialisation and break-even durations across the board ($p<0.01$). This is also compatible with a similar correlation found by Ali et al. (1995). It suggests that shorter commercialisation durations also leads to shorter break-even durations when the effects of explanatory variables are overlooked, and vice versa. Nonetheless, when the predicted value of commercialisation durations was included as an explanatory variable in the second model on break-even durations, no significant association was detected.[6] Taken together, the association between firms' ability to achieve a first mower advantage, as well as the commercial success of innovations in terms of their potential to generate positive cash flows quickly, appears to be highly dependent on the moderating effects of the included variables capturing different sources of heterogeneity, as well as different kinds of sources of innovations. This also underlines the starting point of this paper that the commercialisation and break-even durations capture two different dimensions of successful innovation, even though they jointly define successful innovations. Another interesting result is that the distribution of both durations is skewed to the left, with median commercialisation duration of 2.0 and a median break-even duration at 1.0.

4.1.1 Commercialisation durations - descriptives

The mean and median of the commercialisation durations across the different nature of innovations, characteristics of firms, and sectors to be used as explanatory control variables are presented in the tables below.

[6] The predicted value of the commercialisation durations avoids problems of collinearity with variable whose coefficients share significant p-values in both models.

Table 4. Commercialisation durations by the nature of innovations (mean and median values).

Nature of innovation	n	Mean duration	Median duration
New to the firm	314	3.64	2.00
Incremental to the firm	202	3.44	2.00
High complexity	223	4.52	3.00
Low complexity	294	2.82	2.00

As could be expected, innovations that are entirely new to the firm, or technologically less familiar compared to previous innovations, appear to have slightly higher mean durations compared to innovations merely embodying minor changes. More significantly, the degree of complexity of innovations seems to explain different mean durations, since innovations of higher complexity clearly are characterised by prolonged durations by their means. The complexity of innovations seems to be a necessary variable to include in the models to be estimated, in order to capture heterogeneity across the complexity of different types of innovations.

Table 5. Commercialisation durations by the size of firms.

Characteristics of firm	n	Mean duration	Median duration
Firm size 1–9 employees	92	3.27	2.00
Firm size 10–999 employees	281	3.36	2.00
Firm size 1000+ employees	125	4.43	3.00

Turning to the size of firms, the differences in mean commercialisation durations are negligible when moving from innovations with an origin in firms with less than 10 employees, to the middle firm size group with 10–999 employees. Nonetheless, from the table it is clear that innovations originating from the largest firms with more than 1000 employees share longer commercialisation durations. This result suggests that large firm size, in fact, does not offer an advantage in terms of shortening commercialisation durations. Nonetheless, it might also reflect the different nature of innovation in larger firms in the degree to which they are involved in the development of more complex innovations that required a higher dedication to R&D. Alternatively, they might take advantage of their greater strategic freedom with respect to being better able to intentionally time product launches compared to smaller firms, for example in anticipation of changing trends in demand in the markets, or their competitive positioning.

Table 6. Commercialisation durations by the sector of origin of innovations.

Origin of innovation	n	Mean duration	Median duration
High R&D-intensive industries			
Electronics sector	53	3.68	2.00
Chemicals sector	44	6.59	4.50
Instruments sector	68	4.13	3.00
Machinery sector	141	3.11	2.00
Low R&D-intensive industries			
Metals sector	80	3.17	3.00
Foodstuffs sector	43	2.64	2.00
Forestry sector	39	3.16	2.00
Other manufacturing sectors	41	2.45	2.00

The origin of innovations in different sectors clearly differentiates between different mean durations, motivating the inclusion of the sectoral dummies in the model. Innovations originating from the R&D-intensive electronics, chemicals and instruments sectors are characterised by longer commercialisation durations, while innovations originating from the more traditional low R&D-intensive metals, foodstuffs, forestry and other miscellaneous manufacturing sectors have shorter durations. With reference to the discussion above, these differences probably relate to differences in the nature of the underlying knowledge bases, incentives and requirements of firms to become engaged in more systematic R&D activity, which prolong the durations. In the traditional low R&D-intensive industries, the nature of competition (for example, shorter product life cycles) appears to put pressure on firms to shorten their commercialisation durations.

4.1.2 Break-even durations - descriptives

The mean and median of the break-even durations included across the different nature of innovations, characteristics of firms, and sectors to be used as explanatory control variables are presented in the tables below.

Table 7. Break-even durations by the nature of innovations.

Nature of innovation	N	Mean duration	Median duration
New to the Finnish market	82	1.80	1.00
New to the global markets	264	2.50	2.00
Exported	310	2.48	2.00
Not exported	46	1.25	1.00
Patented	198	2.85	2.00
Not patented	158	1.67	1.00

When looking at mean break-even durations, the novelty of innovations is approached from the market viewpoint. In this set-up, innovations new to the global markets are associated with longer break-even durations compared to those that are new merely to the Finnish market. Likewise, exported innovations have longer break-even durations compared to innovations that merely serve the domestic markets. In fact, both of these results go against the discussion above where I suggested that the relationship should be the opposite - an observation that awaits further interpretation in the duration analysis that follows. However, in cases where innovations are patented, break-even durations are clearly longer compared to non-patented innovations, motivating the inclusion of this variable in the modelling of break-even durations.

Table 8. Break-even durations by the characteristics of firms.

Characteristics of firm	n	Mean duration	Median duration
Firm size 1–9 employees	55	2.34	2.00
Firm size 10–999 employees	206	2.41	2.00
Firm size 1000+ employees	85	2.27	2.00

Again, the size of firms does not seem to differentiate between durations since the deviancies of the mean break-even durations from the corresponding average are small. Clearer differences emerge in terms of the origin of innovations by sectors and the R&D-intensity of industries, according to Table 9. Again higher R&D-intensity is associated with longer durations, while innovations originating from the low-R&D-intensive industries have the shortest durations. The obvious example of the former is again the chemicals sector, while the lower mean break-even durations in the foodstuffs sector is the obvious example of the latter. Hence, this also supports the inclusion of sectoral dummies also in the estimations of break-even durations. The different nature of markets and competition, and varying levels of technological opportunities, associated with different sectors appear to matter. Nonetheless, the sectoral origin of innovations appears less relevant for the break-even durations, compared to the commercialisation durations.

Table 9. Break-even durations by the sector of origin of innovations.

Origin of innovation	n	Mean duration	Median duration
High R&D-intensive industries			
Electronics sector	33	2.68	1.00
Chemicals sector	28	3.09	2.00
Instruments sector	56	2.57	2.00
Machinery sector	98	2.10	1.00
Low R&D-intensive industries			
Metals sector	54	2.74	2.00
Foodstuffs sector	27	1.84	1.00
Forestry sector	23	2.03	1.00
Other manufacturing sectors	29	1.55	1.00

4.2 The determinants of commercialisation and break-even durations

Following the descriptive analysis of the contribution of variables controlling for different sources of heterogeneity across the durations, the next step is to move to estimating the models using the Weibull and logistic parametrisations as presented in Table 2. The approach is to first approximate the shape of the hazard function using the non-parametric Kaplan-Meier estimates as defined above. Thereafter I present the estimation results of the Weibull and logistic parametrisations of the models that include the explanatory variables. Each full model, including the explanatory variables, is subsequently reduced to a simpler model in which insignificant variables are dropped based on stepwise log likelihood ratio tests and the related p-values. For final confirmation of the most appropriate model for modelling the commercialisation and break-even durations, I rely on residual analysis based on the integrated hazard defined in equation (8).

The Kaplan-Meier estimates are plotted against the durations to trace the shape of the approximated hazard function for analysing the nature of the duration dependency, and the relevance of the Weibull and logistic parametrisations of the duration models. The estimation results are presented by listing the coefficients of the explanatory variables and their p-values in the subsequent tables. A positive sign of the coefficient increases the probability that the duration ends, and thereby shortens the duration, while a negative sign decreases the probability and prolongs the duration. The number of total and censored observations, the value of the estimated parameter α at the data means to indicate the nature of duration dependency, as well as the value of the log likelihood and the LR test statistic are at the bottom of the table. In this set-up, the LR test statistic denotes the overall significance of the models, as indicated by the associated p-value. The statistic tests the null hypothesis that all coefficients are simultaneously equal to zero and hence have no effect on the durations. The results of the stepwise log likelihood ratio tests are summarised by presenting the restrictions imposed, the values of the related log likelihood, the LR test statistics, as well as the degrees of freedom involved. Following the estimation results of the reduced models the results of the residual analysis are presented.

4.2.1 Commercialisation durations - estimation results

The approximated hazard rates based on the Kaplan-Meier estimates is presented in Figure 2 across the whole range of commercialisation durations.

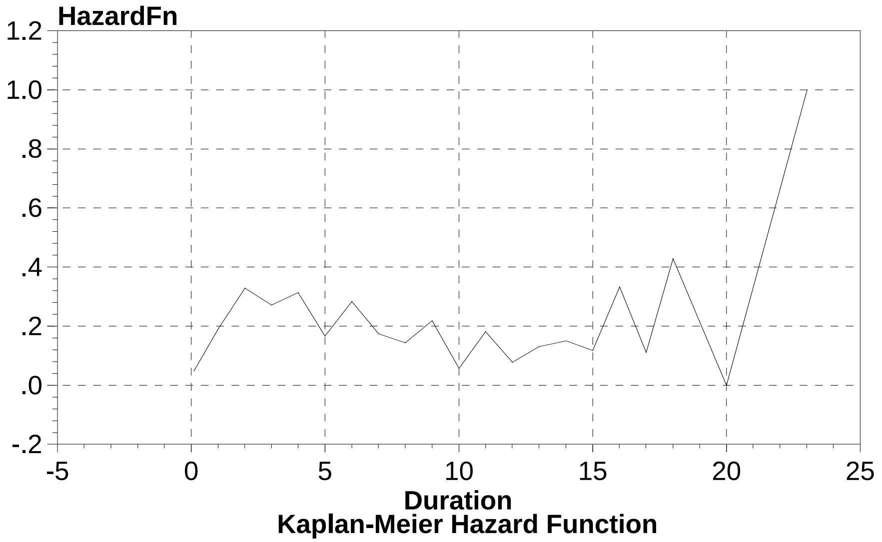

Figure 2. Hazard rates of the commercialisation durations based on the Kaplan-Meier estimates.

According to the figure, the commercialisation durations exhibit positive duration dependency (increasing hazard rates) up until a duration of 2 years, where after there appears to be a reversal of the duration dependency from positive to negative (increasing to decreasing hazard rates). When the durations approach 15 years, the pattern becomes highly erratic, foremost due to the limited number of observations at the tail of the distribution. In plain text, the interpretation is that the probability of an innovation reaching commercialisation appears to increase during the first two years of the duration, after which the tendency is reversed and innovations face declining probabilities of commercialisation. Given that the median commercialisation duration also is 2 years, the Weibull parametrisation thus seems to an appropriate one for a large share of the durations. The reversal of the duration dependency from positive to negative after that nonetheless also speaks in favour of the logistic parametrisation of the duration model, as suggested above.

Table 10. Estimation results of the models on commercialisation durations (significant coefficients at 0.10 level in bold).

	Weibull		Logistic	
Variable	Coeff.	p-value	Coeff.	p-value
Constant	**-1.498**	0.000	**-1.094**	0.000
Control variables				
FNOVEL	**0.001**	0.047	**-0.001**	0.024
COMPLEX	**-0.254**	0.010	**-0.367**	0.000
FSIZE1	0.065	0.568	0.020	0.863
FSIZE3	0.043	0.667	-0.049	0.651
ELECTRO	-0.009	0.955	-0.079	0.604
CHEM	**-0.468**	0.000	**-0.377**	0.015
INST	0.040	0.782	-0.030	0.849
METAL	-0.013	0.908	-0.095	0.465
FOOD	**0.263**	0.103	0.167	0.316
FOREST	-0.137	0.232	0.102	0.498
OTHER	-0.050	0.754	-0.110	0.576
Substantial variables				
CUSDEM	**0.164**	0.011	**0.216**	0.001
UNIVRES	**-0.231**	0.000	**-0.217**	0.000
SCITECH	**-0.071**	0.050	**-0.071**	0.062
CONSUP	0.080	0.127	-0.003	0.954
REGLEG	-0.012	0.739	-0.031	0.396
COMPET	-0.017	0.675	0.000	0.998
Observations	521		521	
Censored obs.	32		32	
α	1.220		1.964	
Log-L	-691.477		-682.066	
LR [χ^2(df=17)]	97.322	0.000	91.583	0.000

A first inspection of the results reveals that the familiarity of an innovation to the firm, FNOVEL, it's degree of complexity, COMPLEX, as well as the origin of innovations from the chemicals sector, CHEM, or the foodstuffs sector, FOOD, are the primary observed sources of heterogeneity across the different commercialisation durations. In the case of COMPLEX, the coefficient is negative and highly significant ($p<0.01$) according to both parametrisations. This suggests that a higher degree of complexity of the innovations prolong their commercialisation durations as expected.

The negative and highly significant ($p<0.01$) coefficient of the sectoral dummy CHEM confirms the descriptive results above on the longer commercialisation durations that characterises the chemicals sector. Here the obvious example is the pharmaceuticals sector, in which high R&D investments and the related requirements to undertake clinical research prior to the commercialisation of an innovation prolong the durations. In the case of the foodstuffs sector, the coefficient of FOOD is positive but weakly significant ($p<0.10$) in the Weibull parametrisation, while the sign remains the same but the coefficient becomes insignificant in the logistic parametrisation. Hence, the nature of markets and competition in this sector seems to differ and shorten the commercialisation durations for those reasons. Somewhat surprisingly, the degree of familiarity of innovations to the firms by the coefficient of the variable FNOVEL shortens the durations by the positive and moderately significant coefficients ($p<0.05$), contrary to what was expected. Likewise surprising is the fact that firm size, by the variables FSIZE1 and FSIZE3, has no apparent effect on the durations.

When moving to the substantial variables capturing the different sources of innovations as the focus of this paper, an interesting general result is that they clearly appear as more important in this context compared to the variables capturing sources of heterogeneity. The main drivers of shorter commercialisation durations are sources of innovations related to collaboration with customers, CUSDEM. The related coefficient is positive and highly significant ($p<0.01$) according to both parametrisations. The effect of sources related to basic or applied novel research, assimilated through collaboration with universities or research organisations, UNIVRES, as well as scientific breakthroughs and new technologies adding to the general pool of knowledge, SCITECH, appears to be the opposite. The coefficient of UNIVRES is negative and highly significant ($p<0.01$) according to both the Weibull and logistic parametrisation, while the coefficient of SCITECH is negative and moderately significant ($p<0.05$) according to both parametrisations. The variables CONSUP, REGLEG and COMPET have no effect on the durations. According to the LR test statistics, the null hypothesis that all coefficients are simultaneously equal to zero is rejected ($p<0.01$).

Table 11. Likelihood ratio (LR) tests of the effects of dropped variables on the models on commercialisation durations (significant LR test statistics at 0.10 level in bold).

	Weibull			Logistic		
	LR	p-value	df	LR	p-value	df
FNOVELTY=0	**3.336**	0.066	1	0.088	0.766	1
COMPLEX=0	**7.914**	0.004	1	**16.225**	0.000	1
FSIZE1=FSIZE3=0	0.460	0.794	2	0.409	0.818	2
ELECTRO...OTHER=0	**17.730**	0.013	7	10.190	0.178	7
CUSDEM...COMPET=0	**35.398**	0.000	6	**35.876**	0.000	6

By and large, the results of the stepwise LR tests are in line with those in Table 10. Reading down the table, FNOVELTY, COMPLEX, the sectoral dummies ELECTRO--OTHER, as well as the substantial variables CUSDEM--COMPET indeed appear as relevant to include in the reduced models of both parametrisations by their LR test statistic. Based on Table 10, the relevant sectoral dummies are CHEM and FOOD, while CUSDEM, UNIVERS and SCITECH should be selected from the set of substantial variables. Moreover, the effects of the sectoral dummies appear to be weaker according to the stepwise LR tests of the logistic parametrisation. The reduced models of respective parametrisation are presented in Table 12, using the same notation as above.

Table 12. Estimation results of reduced models on commercialisation durations (significant estimates in bold).

	Weibull		Logistic	
Variable	Coeff.	p-value	Coeff.	p-value
Constant	**-1.543**	0.000	**-1.150**	0.000
FNOVEL	**0.001**	0.083	**-0.001**	0.015
COMPLEX	**-0.229**	0.004	**-0.348**	0.000
CHEM	**-0.472**	0.000	**-0.340**	0.015
FOOD	**0.295**	0.049	0.202	0.183
UNIVRES	**-0.212**	0.000	**-0.222**	0.000
CUSDEM	**0.186**	0.001	**0.205**	0.001
SCITECH	**-0.064**	0.053	**-0.072**	0.054
Observations	521		521	
Censored obs.	32		32	
α	1.209		1.955	
Log-L	-693.913		-683.616	
LR [χ^2(df=7)]	92.454	0.000	88.482	0.000

The signs and significance of the variable coefficients remain the same in the reduced models with the exception of FNOVEL and FOOD, which lose some of their significance according to both parametrisations, when compared to the full models. Based on the reduced models, that here are take to represent the final model on the determinants of commercialisation durations, residuals are calculated and saved for further analysis of the fit the Weibull versus the logistic parametrisations. For the sake of clarity, I rely on the descriptive statistics of the residuals to determine their variation across the durations in Table 13. Judged by the lower mean, standard deviation and shorter dispersion of values, the residual of the logistic parametrisation appears to show lesser variation. Hence, the logistic parametrisations evidently provides a more appropriate description of the distribution of the observed commercialisation durations compared to the Weibull parametrisation. The underlying assumption of positive to negative duration dependency of commercialisation durations is thereby further confirmed.

Table 13. Descriptive statistics of residual of the reduced Weibull and logistic models on commercialisation durations.

Integrated hazard	Mean	Std. Dev.	Min.	Max.
Weibull	0.939	0.933	0.002	5.708
Logistic	0.907	0.841	0.000	5.041

4.2.2 Break-even durations - estimation results

The approximated hazard rates based on the Kaplan-Meier estimates is presented in Figure 3 across the whole range of break-even durations.[7]

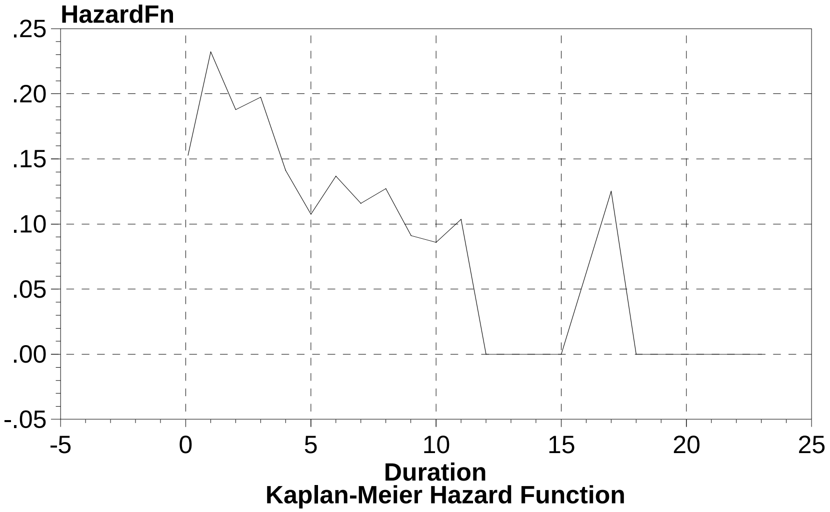

Figure 3. The hazard rates of break-even durations based on the Kaplan-Meier estimates.

[7] Please note that the scale on the y-axis is different when compared to Figure 2, where the hazard rates of the commercialisation durations are presented.

The break-even durations exhibit positive duration dependency (increasing hazard rates) up until 1.5 years. After that, the duration dependency is reversed, and turns negative (decreasing hazard rates) throughout with the exception of a temporary peak at around 17 years. Hence, the interpretation is also similar, namely that the probability of an innovation reaching break-even appears to increase during the first year after it's commercialisation, where after the tendency is reversed and innovations face declining probabilities of break-even. Given that the median break-even duration is 1 year, the Weibull parametrisation thus again seems to an appropriate one for a large share of the durations. The reversal of the duration dependency after that nonetheless speaks also in favour of the logistic parametrisation of the duration model, as suggested above.

Table 14. Estimation results of the models on break-even durations (coefficients significant at 0.10 level in bold).

	Weibull		Logistic	
Variable	Coeff.	p-value	Coeff.	p-value
Constant	-2.818	0.000	-1.906	0.000
Control variables				
MNOVEL	**0.001**	0.078	**0.001**	0.046
EXPORT	**1.153**	0.000	**0.756**	0.000
PATENT	**-0.329**	0.040	**-0.342**	0.052
FSIZE1	-0.204	0.359	-0.185	0.415
FSIZE3	-0.156	0.349	-0.182	0.373
ELECTRO	-0.135	0.634	-0.258	0.409
CHEM	-0.035	0.906	0.024	0.943
INST	0.314	0.253	0.166	0.602
METAL	-0.142	0.555	-0.255	0.322
FOOD	0.313	0.273	0.232	0.460
FOREST	-0.367	0.141	-0.114	0.718
OTHER	-0.114	0.662	0.076	0.819
Substantial variables				
CUSDEM	**0.227**	0.047	**0.244**	0.051
UNIVRES	**-0.346**	0.002	**-0.417**	0.001
SCITECH	-0.060	0.373	-0.046	0.553
CONSUP	0.008	0.936	-0.026	0.813
REGLEG	0.037	0.582	-0.018	0.811
COMPET	**0.227**	0.000	**0.300**	0.000
Observations	511		511	
Censored obs.	167		167	
α	0.782		1.030	
Log-L	-775.920		-782.178	
LR [χ^2(df=18)]	72.396	0.000	57.835	0.000

Among the explanatory variables included in the estimation of break-even durations, the exportability of innovations by the variable EXPORT, and patented innovations, PATENT, appear to be the primary sources of heterogeneity. The coefficients for EXPORT are positive and highly significant ($p<0.01$) according to both parametrisations, confirming the assumed relationship between larger markets, the faster diffusion of innovations, and shorter break-even durations. Nonetheless, the moderately significant ($p<0.05$) and negative coefficient for PATENT suggests that the lesser imitativeness of innovations does not shorten their break-even durations.

The effects of the variable MNOVEL on the durations is not clear-cut, even though the tendency is that the variable shortens the durations as expected by the positive sign of the related coefficient - in the Weibull parametrisation it's level of significance is low ($p<0.10$), in the logistic parametrisations it is moderate ($p<0.05$). An interesting result, when compared to the results of the estimations of commercialisation durations, is the lack of significance of the sectoral dummies.

In these models the substantial variables capturing the different sources of innovations likewise appear as more important compared to the variables capturing sources of heterogeneity. In this set-up, the main driver of shorter break-even durations again appears to be collaboration with customers, CUSDEM, with a positive but only moderately significant coefficient ($p<0.05$) in both parametrisations. Moreover, competitive markets by the variable COMPET, appears to shorten the durations by the positive and highly significant coefficient according to both parametrisations ($p<0.01$). In contrast, the effect of sources of innovations related to basic or applied novel research assimilated through collaboration with universities or research organisations, UNIVRES, again seems to prolong the durations. The coefficient of UNIVRES is negative and highly significant ($p<0.01$) according to both parametrisation. The remaining variables SCITECH, CONSUP and REGLEG have no effect on the durations. According to the LR test statistics, the null hypothesis that all coefficients are simultaneously equal to zero is again rejected in both models ($p<0.01$).

Table 15. Likelihood ratio (LR) tests of the effects of dropped variables on the models on break-even durations (significant LR test statistics at 0.10 in bold).

	Weibull			Logistic		
	LR	p-value	df	LR	p-value	df
MNOVELTY=0	**3.946**	0.047	1	**3.891**	0.048	1
EXPORT=0	**29.205**	0.000	1	**9.959**	0.001	1
PATENT=0	**4.635**	0.031	1	**4.004**	0.045	1
FSIZE1=FSIZE3=0	1.436	0.487	2	1.247	0.535	2
ELECTRO...OTHER=0	7.469	0.381	7	4.066	0.772	7
CUSDEM...COMPET=0	**29.652**	0.000	6	**32.087**	0.000	6

Again the results of the stepwise LR tests are in line with those in Table 13 as could be expected. The significance of the LR statistics of MNOVELTY, EXPORT, PATENT, as well as the substantial variables CUSDEM--COMPET all speak in favour of including them in the reduced models of both parametrisations. The firm size dummies FSIZE1--FSIZE3, as well as the sectoral dummies ELECTRO--OTHER may be dropped as insignificant. There are no noticeable differences in these respects between the Weibull and logistic parametrisations. The reduced models are presented in Table 16.

Table 16. Estimation results of reduced models on break-even durations (coefficients significant at 0.10 level in bold).

	Weibull		Logistic	
Variable	Coeff.	p-value	Coeff.	p-value
Constant	**-2.820**	0.000	**-1.989**	0.000
MNOVEL	**0.001**	0.083	**0.001**	0.038
EXPORT	**1.104**	0.000	**0.722**	0.000
PATENT	**-0.349**	0.015	**-0.372**	0.027
UNIVRES	**-0.348**	0.001	**-0.414**	0.000
COMPET	**0.228**	0.000	**0.288**	0.000
CUSDEM	**0.205**	0.069	**0.222**	0.070
Observations	511		511	
Censored obs.	167		167	
α	0.770		1.023	
Log-L	-780.638		-785.165	
LR [χ^2(df=6)]	62.958	0.000	51.866	0.000

The signs and significance of the variable coefficients remain more or less the same across the board in the reduced models, suggesting that little is lost by dropping variables based on the LR tests. Based on the reduced models, that here are take to represent the final model on the determinants of break-even durations, residuals are calculated and saved for further analysis of the fit the Weibull versus the logistic parametrisations. Again, I rely on descriptive statistics of the residuals, based on the integrated hazard function, to determine their variation across the durations in Table 17. The results indicated that the logistic parametrisation once more is the more appropriate one, based on the lower mean, standard deviation and shorter dispersion of values. Accordingly, the assumption of positive duration dependency, turning into negative over the duration, is confirmed further also in the case of break-even durations.

Table 17. Descriptive statistics of residual of the reduced models on break-even durations.

Integrated hazard	Mean	Std. Dev.	Min.	Max.
Weibull	0.688	0.645	0.018	4.918
Logistic	0.664	0.531	0.009	2.867

5. A synthesising discussion

5.1 The nature of commercialisation and break-even durations

The purpose of this paper has been to empirically investigate the relationships between different types of sources of innovations and two specific dimensions of successful innovations. The first dimension captures firms' ability to achieve first mower advantages through shorter commercialisation times. The second dimension captures the commercial success of innovations through their potential to return positive cash flows quickly, once they have been introduced to the market. The point of departure was that the assimilation of different sources of innovation constitutes a necessary condition for achieving first mower advantages and commercial success on the market. The empirical analysis draws on a survey of some 600 innovations developed in various manufacturing industries in Finland during the 1980s and 1990s. The data is applied to duration analysis, an econometric technique for modelling the length of durations of particular states. An important issue in this context was to control for sources of heterogeneity across innovations by their different characteristics, the nature of the commercialising firm, and sectors of origin, that moderate the relationships between different sources of innovations and the durations. Duration analysis also incorporates censored dependent variables in cases where the durations were ongoing at the time of data collection.

A first observation is that both commercialisation and break-even durations are surprisingly short with a mean of 3.5 years, and 2.3 years respectively. An assessment of how these results compare to previous studies is difficult due to the use of incompatible definitions and measurements of durations and innovations. Nonetheless, it seems fair to conclude that firms face relatively narrow 'windows of opportunity' in this respect, and need to react swiftly once they emerge. This type of conclusion also appears to be in line with observations on the changing nature of competition due to developments in ICT, as well as globalisation, and the related reduction in product life cycles (Cooper 2001). Commercialisation and break-even durations also appear to be related, since shorter commercialisation times correlate significantly with shorter break-even times, and vice versa. This is in line with the results in Ali et al. (1995), and indicates that firms are able to achieve shorter commercialisation times without 'cutting corners' during the development of innovations from the viewpoint of their commercial success in the market. Despite this correlation, the predicted values of commercialisation durations had no apparent effect on the length of break-even durations in the estimations, and were hence omitted.

One important issue is the dependency of durations on time, since it reveals the nature of the durations and suggests a relevant parametrisation of the duration models. The skeweness of both commercialisation and break-even durations suggests that the majority of innovations reach the market and break even with increasing probabilities over time up until a certain threshold in elapsed years. After this threshold, inhibiting forces appear to set in, which prolong the durations and decrease the probability of commercialisation and break-even. This shift from positive to negative duration dependency was also confirmed, based on Kaplan-Meier estimates and an analysis of the variability of the residuals over the durations.

The analysis of model specification suggested that a logistic parametrisation was more appropriate in both cases. In the case of the commercialisation durations, this result is somewhat surprising given that all innovations included have been commercialised in the markets, with the probability of commercialisation eventually reaching unity. Nonetheless, a few very long durations at the tail of the distribution, after the removal of evident outliers, is apt to place some bias in favour of negative duration dependency (Allison 1984). In the case of the break-even durations, the distribution shows less variability in this respect. The reversal from positive to negative duration dependency can hence be given greater analytical content. It might reflect the dynamics of competition on the markets in cases where the prospects of an innovation to generate a positive cash flow dampens if it does not achieve a first mower advantage due to prolonged commercialisation times and the emergence of imitative innovations.

5.2 Sources of heterogeneity and strategic trade-offs

The issue of heterogeneity across innovations was acknowledged by incorporating dummy control variables in the models to moderate between the nature of innovations and their durations. At the same time, they capture various trade-offs that are manifested in the strategic choices that firms face during innovation. In the case of commercialisation durations, high complexity innovations are associated with prolonged durations, while the familiarity of the innovations to the firms had an inconclusive effect. With respect to the complexity of innovations, the results are in line with previous research (compare to Griffin 1993; Ali et al. 1995; Karlsson & Åhlström 1999). Hence, there is an evident trade-off between becoming engaged in high complexity innovations, and the aspirations of firms to be first-mowers in the market. The effect of the familiarity of the innovations to the firms conflict with previous results (compare to Maidique & Zirger 1984; Schoonhoven et al. 1990). This might suggest that there is also a set of moderating variables to be included in analysing this relationship in greater detail - a possible source of unobserved heterogeneity that remains outside the scope of this paper due to non-availability of relevant data. As suggested by McDonough & Barczak (1992), firms differ in the problem-solving orientation, or absorptive capability, to assimilate less familiar technologies (Cohen & Levinthal 1990). Familiarity can also be defined in many different ways, ranging from technological familiarity as in this paper, to the degree to which the innovation fits into existing synergies in R&D, production and marketing between various product lines within the firm (Danneels & Kleinschmidt 2001).

The effects of the size of the commercialising firm and the sector of origin of innovations on the commercialisation durations are negligible. According to the descriptive analysis the largest firms with more than 1000 employees appeared to be associated with longer mean durations. Based on insignificant p-values of the coefficients and stepwise LR statistics tests, the variables on firm size were nonetheless dropped from the reduced models as irrelevant. Contrary to what is suggested by Griffin (1993) and Ali et al. (1995), among others, more R&D resources, which assumedly comes with larger firm size, does not enhance firms' ability to reduce commercialisation times. However, the origin of innovations in different sectors differentiated between mean commercialisation durations in the sense that innovations originating in sectors characterise by higher R&D-intensities had longer durations compared to those in the less R&D-intensive sectors. The underlying assumption here was that different sectors capture the characteristics of the knowledge base that firms draw upon, as well as the technological opportunities, nature of markets and competition that they face (Malerba & Orsenigo 1997; Marsili 2001). In the duration analysis the only significant sectoral dummy variables were those capturing innovations originating from the chemicals and foodstuffs sectors. In the chemicals sector, innovations face prolonged durations primarily due to stringent requirements for clinical research prior to commercialisation (Gambardella 1995). In the foodstuffs industry, short product life cycles and price competition are probably the main factors that enforce shorten commercialisation durations (Palmberg 2001).

Since break-even durations capture a different dimension of successful innovations, different control dummy variables were included. In this context, the degree of novelty of innovations to the markets appears to shorten break-even durations as expected, although the results are inconclusive. This result hence offers some further confirmation to the relationships, discussed above, between commercialisation and break-even durations by suggesting that a first-mower advantage will also generate positive cash flow more quickly. The effects of exported and patented innovations are much clearer, due to the higher level of significance of the related coefficients. As expected, an exported innovation can take advantage of a larger market that evidently enhances the possibilities to achieve a positive cash flow quickly. The prolonging effects of patented innovations on break-even durations is surprising, given that stronger property rights over the innovation should block the entry of rival imitative innovations, and thereby increase the prospects of generating a positive cash flow quickly (Levin et al. 1987). The appropriate interpretation of this result instead appears to be that patented innovations involve more demanding development work due to the complexity and novelty of the underlying technologies, with the prolonging effect.

The size of the commercialising firm and the sector of origin of the innovations have no apparent effect on the break-even durations, and were hence dropped from the reduced models following stepwise LR tests. Despite this the result is interesting since it suggests that the commercial success of innovations is not dependent on the particular firm size and sectoral setting wherein innovations are developed. In the case of firm size, one might easily imagine that large firms have greater marketing resources that would shorten break-even times. Larger firms are also typically incumbents in the markets, with well-developed complementary assets in terms of supplier, retailer and customer relationships that should enhance the saleability of new innovations (Teece 1986). On the other hand, smaller firms might show greater flexibility in response to developments in the markets, and may be more focused on particular market niches where the potential to extend sales are greater. In the case of the sector of origin of the innovations, the result goes against common assumptions that certain R&D-intensive industries provide greater scope for commercial success compared to the more traditional industries characterised by technological maturity and saturated markets...at least in a short run perspective (compare to Palmberg 2001).

5.3 Sources of innovations, commercialisation and break-even durations

The substantial variables capturing the different sources of innovations were derived using a principal component analysis (PCA) on the original set of variables on the origin of innovations and the importance assigned to different collaborative partners during innovation (Palmberg 2002). The PCA singled out six different sources of innovations that were related to the chain-linked model of innovation for analytical purposes. They capture sources related to customer demand and market niche, collaboration with universities and research organisations, scientific breakthrough and new technologies adding to the general pool of knowledge underlying innovation, collaboration with consultants and suppliers, regulations and standards, as well as competitive pressure due to price competition and rival innovations. The related variables were included in the modelling of commercialisation and break-even durations on an explorative basis.

An important general result is that the effects of different sources of innovations come out as significant based on p-values for three out of six variable coefficients, as well as stepwise LR tests. Hence, different sources of innovations are significant in conditioning firms' ability to shorten commercialisation and break-even durations, even when the effects of observed heterogeneity are accounted for. Conversely, this underlines the starting point of this paper in the diversity in the sources of innovations that cut across both firm and sectoral boundaries. Another general result is the fact that different sources have similar effects on commercialisation and break-even durations, with some exceptions. This further confirms the discussion above about the relationships between commercialisation and break-even durations, and their joint contribution to the definition of successful innovation. Moreover, the results remain intact irrespective of the choice of model parametrisation, and thus appear to be robust.

The importance of innovation in line with customer demand for successful innovation is a key result of most previous studies, whatever definition of success is applied (compare to the reviews in Cobbenhagen 2000; Cooper 2001). This result gets further confirmation in this paper, with some modification. Sources of innovations related to customer demand and market niche significantly shorten commercialisation durations, implying that customer oriented innovations have a higher probability of reaching the market quickly. A similar interpretation seems to be valid with respect to break-even durations, even though the related coefficient loses some of it's significance in the reduced model. A parallel can here be drawn to the chain-linked model of innovation, and it's emphasis on continuous feedback from customers as the future users of innovations throughout the innovation process (Kline & Rosenberg 1986). Moreover, the importance of competent lead users as sources of innovation and their success is well documented, among others by von Hippel (1988) and Eliasson (1995). What remains unclear in this paper is the exact nature and content of customer orientation, which might range from in-house market analysis and short-term interactions with customers, to long-term durable collaboration.

An especially robust result is the highly significant but opposite effect of sources of innovations related to collaboration with universities and research organisations. Hence, while collaborative research with the universities or research organisations open up new opportunities to innovate, the consequences are prolonged commercialisation and break-even times of innovations. This result is nonetheless intuitive to the degree that complementary research at the universities or research organisations reflects science-based innovation and higher R&D expenditures, which assumedly prolong both durations (data on firms' investments in R&D was not available for this study). The result also speak in favour of making an analytical distinction between the success of innovations in the short and long run. Clearly, a science-based innovation, characterised by prolonged commercialisation and break-even times, might nonetheless be highly successful in the longer run due to accumulated monopoly rents, once a significant market position is reached - a new breakthrough pharmaceutical is an obvious example of this.

Apart from the similar effects of customer orientation and science-based innovation on both durations, an important difference is that scientific breakthroughs and new technologies prolong commercialisation durations, while there is no corresponding effect on the break-even durations. Despite the application of PCA to single out sets of distinct types of sources of innovations, an intuitive interpretation is that the related variables likewise capture science-based innovations with similar consequences for commercialisation times. However, with reference to the chain-linked model, these types of sources of innovations relate to the general pool of knowledge available to all firms in a particular sector, whereby they will not acquire any one innovation as a unique source of commercial success. Therefore, they will not distinguish between different lengths of break-even durations. In this context, moderating variables capturing firms different absorptive capabilities could again extend the analysis further in an interesting direction (compare to Cohen & Levinthal 1990).

Finally, an interesting result is the significant effect of variables capturing competitive pressure as a source of innovations in shortening break-even durations. Several interpretations are possible here. One interpretation could be that the presence of competitive threats increases firms sensitivity to developing complementary assets in the upstream and downstream markets. These complementary assets might include establishing close relationships with suppliers, retailers and customers, which fend off price competition and rival innovations. They might thus enable innovations to break-even quickly despite weaker appropriability conditions (compare to Teece 1986). On the other hand, competitive pressure might reflect depleted technological opportunities and saturated markets, as suggested earlier in this paper, and hence point towards the prevalence of different types of innovations in competitive sectors. Induced by competition, firms probably have greater incentives to innovate incrementally, whereby lesser R&D expenditures and shorter commercialisation times are also reflected in shorter break-even times.

5.4 Limitations related to the definition of successful innovations

Before concluding the paper, a discussion on the limitations of the analysis undertaken here is warranted, which should accompany the drawing of managerial and policy implications from the findings. At this point I have to return to well-charted waters, since most of these limitations are due to difficulties in defining successful innovations. I argue that this paper advances the issue due to the uniqueness of the data at hand, as well as the application of relatively subjective definitions of success through the measured commercialisation and break-even times of innovations. Nonetheless, a first limitation stressed repeatedly in this paper, is that these definitions only capture two specific dimensions of successful innovation. Even though commercialisation and break-even durations evidently are related, and thus jointly contribute to success, the conceptual problem in this context is that the relationship between the durations, market shares, profitability and growth at the firm level is unclear. In the relevant literature, there is empirical evidence both for and against such a relationship, which obviously would be important to establish since the ultimate goal of innovation is sustained firm profitability (Lambert & Slater 1999). This is also a direction in which an extension of the analysis in this paper could go, given that financial data on the firm level could be integrated with data on individual innovations in a sensible way.

The relationship between commercialisation and break-even durations of innovations, and the profitability of firms, also highlights the analytical relevance of distinguishing between success in the short term and long term, as hinted already above. In this paper, my emphasis is on the success of innovations in the short term, by their ability to achieve a first mower advantage through shorter commercialisation times, and commercial success through generating a positive cash flow quickly. Furthermore, the difference between the success of innovations is one of degree, due to the focus on commercialised innovations and the particular methods used for their identification that might have introduced a survival bias. Accordingly, is seems clear that the interpretation of the effects of the different explanatory variables on the durations also have to be read in this light. One such interpretation concerns the prolonging effects of the complexity of innovations, their patentability, and resort to collaboration with universities and research organisations during their development. In all these cases, firms might have to forego advantages of being first in the markets, and achieving commercial success quickly with their innovations, with the option of instead creating a sustained competitive advantage in their market in the longer term. The literature is rich in examples of science-based, radical, innovations with disruptive effects for competing firms and whole industries (compare to Tushman & Anderson 1986). Related to this is also the question of appropriability, in so far as quick success comes at the cost of not being able to fend off competitors, appropriate profits and sustain positive cash flows (Levin et al. 1987).

Further limitations relate to specific definitions used in this paper. The assumption made that shorter commercialisation reflects firms ability to achieve a first mower advantage is open for scrutiny, despite the fact that close to 80 percent of all innovations were considered new to the global markets by the respondents. Moreover, imitative innovation might also be successful for various other reasons, the primary one being that excessive risks might be avoided (Freeman & Soete 1997). It also seems clear that the pros and cons of different commercialisation strategies might vary over the industry life cycle, or by the overall position of firms in their markets. In fact, this issue relates back to a larger theoretical discussion on first mower-advantages in the strategic management literature, a proper review of which is outside the scope of this paper (Lieberman & Montgomery 1988; compare also to Kerin et al. 1992; Robinson et al. 1992). While this issue is an obvious point for further research, it is sufficient to state here that my measure of commercialisation times can merely function as a rough proxy for first mower advantages within the confines of the particular market niche that the innovation is intended to fill.

Finally, the definition of break-even is subject to the assumption that the point of break-even captures the point in time when the innovation started to generate a positive cash flow, rather than the point in time when accumulated positive cash flows exceeded accumulated investments throughout the innovation process. Even though the results speak in favour of the former definition, there might be deviations in the interpretations of the respondents that affect the results. Therefore, a further avenue of future research would be to complement the data on the durations with data on cumulative investments and sales at the product level to check for consistency - an ambitious task requiring close collaboration with the firms.

5.5 Policy implications

Based on the literature review and data analysed in this paper, and acknowledging the limitations discussed above, the following four policy implications might be drawn. First of all, it is clear that the success of innovations is a multi-faceted issue that needs careful consideration from a policy viewpoint. Although this paper has approached the issue from two specific definitions of successful innovations, it might be justified to set policy goals by a range of other definitions of success, and related indicators. The literature reviewed here has suggested many different ways in which firms might succeed with their innovations, ranging from their technical novelty, sales or market shares, and their deviance from the financial break-even, to the timeliness of innovation processes, as well as to their commercialisation and break-even times as done in this paper. Likewise, firms are engaged in many different innovation processes simultaneously, whereby the nature and strength of the relationships between the chosen indicators and long-term profitability and growth at the firm level are fuzzy.

The main point to be made in this context is to propagate for a better awareness of the multi-faceted nature of the success of innovations in designing policies and setting objectives. Accordingly, one might consider different types of policy schemes for achieving different types of success, depending on the objectives. For example, if the objective is to increase the technical novelty of innovations with the purpose of enhancing spillovers, policies promoting networking throughout the innovation process might be appropriate. On the other hand, if the objectives are related to timeliness, or shorter commercialisation and break-even times, a more viable option might be the fostering of user-producer interaction, as well as the provision of complementary R&D and other resources to speed up the process. Generally speaking, it would seem appropriate to be clear about the policy objectives and the underlying policy choices, since different types of success might also conflict with each other in their contribution to the long-term firm profitability and growth. A policy relevant extension of this study would be an attempt to map, in greater detail, the effects of different types of policy options, for example different types of R&D funding schemes, on different indicators of the success of innovations.

When turning to the empirical results, a second policy implication relates to issues of the timing of policy intervention. Even though it is difficult to judge 'how quick is quick' due to the lack of comparable results on the durations of innovations, I suggested that both the mean commercialisation and break-even durations are short. Innovation processes unfold rapidly following the identification of a market need and the point in time when the basic idea was voiced within the firm, to commercialisation, and onward towards generating a positive cash flow. Given that firms thereby also face 'narrow windows of opportunities' to innovate, policymakers likewise face 'narrow windows of opportunities' to promote innovations. Thus, this is another viewpoint that warrants proper attention in policy design. One direct and concrete consequence would be to streamline decision-making in line with the need for speed during innovation. Another issue relates to the identification of the appropriate point in time during the innovation process, at which policy intervention of a specific kind has the greatest effect. Firms will obviously face different bottlenecks and problems during the invention stage, compared to the design, testing production or distribution stages of a typical innovation process (compare to the discussion of the chain-linked model of innovation in section 2.1). In addition, there are important sectoral differences in the commercialisation and break-even durations due to the different nature of technologies, markets and competition. These sectoral differences should also be acknowledged and taken into account.

Thirdly, and related to the first point, the results clearly point towards certain trade-offs between the nature of innovations and their durations. From a policy viewpoint, these trade-offs translate into different choices that a policy maker might have to make in the design of policy. Clearly, an objective to decrease commercialisation times is more difficult in the case of complex innovations, which involve the combination of different technologies and related components. Similarly, in so far as patented innovations at the technological frontier require more development effort, there are poorer prospects for policies aiming at the speeding up of break-even times. Thus, the question here is really one of trading different choices against each other, and it underlines further the multi-faceted nature of the success of innovations. Clearly, innovations differ greatly in terms of the underlying knowledge base, both in observable and unobservable ways. Accordingly, there is a strong case for tailored policy intervention, not only due to sectoral differences in technologies, markets and the nature of competition, but also due to qualitative differences across innovations within sectors and firms.

The fourth, and final, policy implication derives from the signs and significance of the substantial variables capturing the effects of different sources of innovations on the durations. From the results, it is possible to suggest best practices based on the profile of innovation processes that achieve fast commercialisation and break-even times. In the case of commercialisation durations, the profile is clearly one where innovations emerge through collaboration with customers in respond to demand in the market place. However, while this result confirms a range of other studies on successful innovation, more insights on the precise nature of customer involvement in the innovation process would be required in order to draw specific policy implication – an issue that goes beyond the scope of this paper. In the case of break-even durations, the profile is slightly different. In addition to collaboration with customers, innovations induced by price competition and rival innovations, in a competitive environment, capture 'best practice' profiles of innovation processes. This is an interesting result, since it suggests that a policy objective to achieve rapid generation of a positive cash flow is viable also in sectors characterised by saturated markets and depleted technological opportunities. Successful innovation, by this indicator, is not only confined to the high-tech sectors where technological opportunities are greater.

6. Conclusions

Empirical research on successful innovations is characterised by the application of a range of different definitions of success, of which firms' abilities to shorten the commercialisation and break-even times of innovations are two that are often discussed. In this paper, I elaborate further on these specific definitions of successful innovations by applying duration analysis for modelling the relationships between different sources of innovations, and the commercialisation and break-even durations as measures of first mover advantages, as well as the commercial success of innovations.

Both the commercialisation and the break-even durations are surprisingly short, although comparisons to previous studies are made difficult by incompatible definition and measurement of innovations and durations. The results also suggest that there is an association between shorter commercialisation and break-even durations, even though this relationship is moderated by various characteristics of innovations and different sources of innovations. Furthermore, the results largely confirm previous research on the effects of different sources of heterogeneity on the durations, due to different characteristics of innovations, which also introduce different strategic trade-offs to firms during innovation. In the case of commercialisation times, high complexity of innovations has a prolonging effect, along with their origin in the R&D-intensive chemicals sector. Innovations new to the firm surprisingly shorten the durations. In the case of break-even durations, market novelty and exported innovations shorten their durations, while patented innovations prolong them.

By and large, the effects of firm size and sector of origin of innovations on the durations appear as far less significant than different sources of innovations. This underlines the importance of incorporating the diversity in sources of innovations in the analysis of successful innovation, which cuts across both firm size and sectoral boundaries. In this context, innovations related to customer demand and market niche shorten both the commercialisation and the break-even durations, and thus appear as crucial for the success of innovations. In contrast, science-based innovations are characterised by longer durations, even though the effects on the success of innovations in the longer run might be subject to different dynamics not accounted for in this paper. Moreover, competitive markets are associated with shorter break-even durations, suggesting that the successful innovations also emerge under conditions of depleted technological opportunities and saturated markets characterised by fierce price competition. Nonetheless, the results are subject to a number of limitations related to differences in success in the short-term and long-term, as well as to the definition of successful innovation through the commercialisation and break-even durations.

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Appendix 1: The principal component analysis

Principal component analysis (PCA) is a multivariate technique used to identify a smaller number of factors, or principal components, to represent relationships between correlated variables in a larger data set. As a rule of thumb, component loadings above 0.5 are regarded as significant. Surrogate variables can be used to represent each component in a regression to deal with collinearity problems if all original variables are included in the model (Hair et al. 1992; Gujarati 1995). In the duration models the PCA is used to single out whichever two variables that receive the highest component loading to represent the underlying principal component, that are taken to represent different sources of innovations. The result is presented below, with the two selected variables in bold (see Palmberg 2002 for details).

Variables[8]	1	2	3	4	5	6
Scientific breakthrough		0.448				**0.612**
New technologies	0.161					**0.852**
Public program		0.612	0.117		0.212	0.119
Market niche				**0.750**		0.136
Customer demand			0.168	**0.811**		
Price competition	0.101		**0.828**			
Rival innovation		0.117	**0.823**	0.132		
Environmental issues					**0.852**	
Regulations, legislation				0.106	**0.820**	
Customers	0.553		0.111	0.483		
Suppliers	**0.678**		0.120			0.327
Consultants	**0.885**	0.187				
Competitors	0.574	0.194	0.263			
Universities	0.187	**0.794**		0.101		
Research organisations	0.407	**0.660**			0.116	0.133
Cumulative	16%	31%	41%	50%	57%	63%

[8] Since the universe of 'all' Finnish innovation is unknown, it has not been possible to motivate and use weighted values of the variables in the principal component analysis.

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Appendix 2: Descriptive statistics of explanatory variables

Table A 2:1. Substantial variables common to all models.

	Mean	Std.Dev.	Min.	Max.	n
UNIVRES	0.544	0.745	0	3	521
REGLEG	1.144	1.145	0	3	521
COMPET	1.248	1.062	0	3	521
CUSDEM	2.562	0.688	0	3	521
CONSUP	0.831	0.822	0	3	521
SCITECH	1.113	1.178	0	3	521

Table A 2:2. Control dummy variables for the model on commercialisation durations.

	Mean	Std.Dev.	Min.	Max.	n
FNOVEL	0.560	0.490	0	1	521
COMPLEX	0.428	0.495	0	1	521

Table A 2:3. Control dummy variables for the model on break-even durations.

	Mean	Std.Dev.	Min.	Max.	n
MNOVEL	0.774	2.719	0	1	511
EXPORT	0.748	2.308	0	1	511
PATENT	0.539	1.023	0	1	511

Table A 2:4. Control dummy variables common to all models.

	Mean	Std.Dev.	Min.	Max.	n
FSIZE1	0.176	0.382	0	1	521
FSIZE2	0.280	0.4492	0	1	521
FSIZE3	0.259	0.4382	0	1	521
ELECTRO	0.096	0.295	0	1	521
CHEM	0.092	0.289	0	1	521
INST	0.119	0.324	0	1	521
MACH	0.278	0.448	0	1	521
METAL	0.153	0.360	0	1	521
FOOD	0.081	0.272	0	1	521
FOREST	0.088	0.284	0	1	521
OTHER	0.073	0.260	0	1	521

Appendix 3: Stepwise models on commercialisation and break-even durations

Table A3:1. Weibull parametrisation of commercialisation durations.

	Model 1		Model 2		Model 3		Model 4		Model 5	
Variable	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Constant	-1.608	0.000	-1.634	0.000	-1.473	0.000	-1.529	0.000	-1.194	0.000
Control variables										
FNOVEL			0.001	0.028	0.001	0.043	0.001	0.064	0.012	0.041
COMPLEX	-0.271	0.006			-0.259	0.008	-0.296	0.000	-0.388	0.000
FSIZE1	0.072	0.527	0.088	0.431			0.138	0.218	0.106	0.327
FSIZE3	0.054	0.593	0.053	0.604			0.130	0.150	0.490	0.960
ELECTRO	0.015	0.925	-0.031	0.839	0.004	0.978			-0.016	0.911
CHEM	-0.449	0.000	-0.512	0.000	-0.478	0.000			-0.520	0.001
INST	0.067	0.638	-0.048	0.725	0.051	0.719			0.013	0.918
METAL	-0.006	0.960	0.035	0.758	-0.017	0.873			0.058	0.958
FOOD	0.274	0.091	0.329	0.038	0.275	0.082			0.263	0.114
FOREST	-0.114	0.315	-0.078	0.495	-0.150	0.177			-0.145	0.206
OTHER	-0.045	0.779	0.057	0.720	-0.049	0.757			-0.055	0.723
Substantial variables										
UNIVRES	-0.221	0.000	-0.256	0.000	-0.232	0.000	-0.250	0.000		
REGLEG	-0.010	0.792	-0.005	0.882	-0.010	0.793	-0.022	0.558		
COMPET	-0.083	0.835	-0.009	0.809	-0.018	0.642	-0.005	0.888		
CUSDEM	0.199	0.000	0.172	0.009	0.163	0.010	0.159	0.010		
CONSUP	0.061	0.210	0.087	0.086	0.081	0.118	0.077	0.132		
SCITECH	-0.066	0.069	-0.090	0.009	-0.071	0.046	-0.076	0.029		
Observations	521		521		521		521		521	
Censored obs.	32		32		32		32		32	
α	1.213		1.215		1.218		1.190		1.182	
Log-L	-693.158		-695.434		-691.707		-700.342		-709.176	
LR [χ^2]*	93.960	0.000	89.408	0.000	96.862	0.000	75.592	0.000	61.924	0.000

* The degrees of freedom vary depending on the number of dropped variables.

Table A3:2. Logistic parametrisation of commercialization durations.

	Model 1		Model 2		Model 3		Model 4		Model 5	
Variable	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Constant	-1.091	0.000	-1.282	0.000	-1.098	0.000	-1.108	0.000	-0.713	0.000
Control variables										
FNOVEL			-0.001	0.068	-0.001	0.023	-0.001	0.022	-0.001	0.050
COMPLEX	-0.367	0.000			-0.369	0.000	-0.384	0.000	-0.495	0.000
FSIZE1	0.019	0.865	0.066	0.569			0.015	0.897	0.043	0.719
FSIZE3	-0.049	0.649	-0.042	0.699			-0.023	0.830	-0.059	0.585
ELECTRO	-0.079	0.597	-0.110	0.485	-0.078	0.606			-0.019	0.903
CHEM	-0.378	0.015	-0.410	0.008	-0.371	0.016			-0.535	0.001
INST	-0.030	0.844	-0.157	0.313	-0.030	0.848			0.028	0.861
METAL	-0.096	0.462	-0.035	0.791	-0.100	0.444			-0.056	0.674
FOOD	0.167	0.318	0.280	0.093	0.153	0.351			0.152	0.381
FOREST	0.101	0.500	0.156	0.299	0.103	0.488			0.028	0.857
OTHER	-0.110	0.575	0.049	0.801	-0.113	0.562			-0.163	0.405
Substantial variables										
UNIVRES	-0.217	0.000	-0.251	0.000	-0.217	0.000	-0.248	0.000		
REGLEG	-0.032	0.394	-0.025	0.505	-0.031	0.397	-0.034	0.349		
COMPET	-0.000	0.993	-0.001	0.989	-0.003	0.930	0.013	0.752		
CUSDEM	0.215	0.000	0.234	0.000	0.217	0.000	0.205	0.001		
CONSUP	-0.003	0.961	0.004	0.946	-0.004	0.943	0.004	0.937		
SCITECH	-0.072	0.059	-0.100	0.008	-0.073	0.056	-0.076	0.047		
Observations	521		521		521		521		521	
Censored obs.	32		32		32		32		32	
α	1.964		1.931		1.963		1.944		1.895	
Log-L	-682.11		-690.179		-682.271		-687.161		-700.004	
LR [χ^2]*	91.494	0.000	75.356	0.000	91.172	0.000	81.392	0.000	55.706	0.000

* The degrees of freedom vary depending on the number of dropped variables.

Table A3:3. Weibull parametrisation of break-even durations.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Variable	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Constant	-2.996	0.000	-2.089	0.000	-2.959	0.000	-2.876	0.000	-2.783	0.000	-2.067	0.000
Control variables												
MNOVEL			0.001	0.056	0.001	0.130	0.001	0.089	0.001	0.063	0.001	0.056
EXPORT	1.157	0.000			1.069	0.000	1.153	0.000	1.135	0.000	1.139	0.000
PATENT	-0.287	0.071	-0.151	0.339			-0.342	0.032	-0.331	0.024	-0.434	0.006
FSIZE1	-0.186	0.405	-0.266	0.243	-0.228	0.314			-0.142	0.504	-0.103	0.652
FSIZE3	-0.151	0.363	-0.091	0.579	-0.177	0.284			-0.132	0.417	-0.084	0.611
ELECTRO	-0.119	0.678	-0.181	0.511	-0.097	0.729	-0.185	0.507			-0.276	0.322
CHEM	-0.004	0.989	0.003	0.993	0.006	0.983	-0.036	0.902			-0.439	0.107
INST	0.331	0.224	0.425	0.136	0.359	0.187	0.260	0.309			0.135	0.624
METAL	-0.134	0.580	-0.281	0.208	-0.149	0.539	-0.155	0.522			-0.107	0.646
FOOD	0.359	0.211	-0.099	0.700	0.405	0.148	0.316	0.274			0.346	0.256
FOREST	-0.346	0.161	-0.383	0.136	-0.259	0.284	-0.347	0.164			-0.303	0.250
OTHER	-0.082	0.756	-0.179	0.516	-0.075	0.775	-0.138	0.602			-0.267	0.302
Substantial variables												
UNIVRES	-0.332	0.003	-0.315	0.006	-0.370	0.001	-0.327	0.004	-0.336	0.002		
REGLEG	0.037	0.591	0.053	0.438	0.052	0.448	0.039	0.555	0.007	0.916		
COMPET	0.232	0.000	0.256	0.000	0.242	0.000	0.222	0.000	0.226	0.000		
CUSDEM	0.259	0.022	0.233	0.042	0.223	0.053	0.228	0.046	0.225	0.048		
CONSUP	0.009	0.927	0.055	0.577	-0.006	0.947	0.001	0.993	-0.008	0.933		
SCITECH	-0.054	0.428	-0.028	0.683	-0.063	0.357	-0.064	0.346	-0.060	0.355		
Observations	511		511		511		511		511		511	
Censored obs.	167		167		167		167		167		167	
α	0.781		0.758		0.780		0.773		0.773		0.760	
Log-L	-777.893		-790.52		-778.23		-776.63		-779.654		-790.746	
LR [χ^2]*	68.448	0.000	43.194	0.000	67.774	0.000	70.974	0.000	64.926	0.000	42.742	0.000

* The degrees of freedom vary depending on the number of dropped variables.

Table A3:4. Logistic parametrisation of break-even durations.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Variable	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Constant	-2.079	0.000	-1.362	0.001	-2.114	0.000	-1.972	0.000	-1.894	0.000	-1.068	0.000
MNOVEL			0.001	0.030	0.001	0.084	0.001	0.047	0.001	0.035	0.001	0.026
Control variables												
EXPORT	0.775	0.000			0.735	0.001	0.761	0.000	0.744	0.000	0.749	0.000
PATENT	-0.297	0.089	-0.312	0.074			-0.357	0.042	-0.361	0.033	-0.488	0.006
FSIZE1	-0.179	0.434	-0.261	0.253	-0.234	0.310			-0.171	0.437	-0.180	0.439
FSIZE3	-0.199	0.332	-0.155	0.448	-0.197	0.339			-0.167	0.399	-0.127	0.542
ELECTRO	-0.244	0.433	-0.270	0.386	-0.203	0.513	-0.288	0.348			-0.354	0.253
CHEM	0.065	0.844	-0.020	0.953	0.081	0.809	0.055	0.868			-0.399	0.221
INST	0.195	0.536	0.223	0.483	0.200	0.529	0.133	0.672			-0.053	0.866
METAL	-0.260	0.314	-0.311	0.222	-0.275	0.289	-0.256	0.317			-0.193	0.463
FOOD	0.269	0.386	-0.002	0.995	0.323	0.298	0.214	0.492			0.210	0.534
FOREST	-0.057	0.855	-0.233	0.467	0.019	0.951	-0.093	0.770			-0.236	0.474
OTHER	0.094	0.778	-0.022	0.947	0.108	0.746	0.054	0.870			-0.067	0.839
Substantial variables												
UNIVRES	-0.401	0.002	-0.379	0.003	-0.442	0.001	-0.406	0.002	-0.403	0.001		
REGLEG	-0.018	0.819	-0.013	0.865	-0.010	0.894	-0.025	0.741	-0.026	0.714		
COMPET	0.312	0.000	0.333	0.000	0.322	0.000	0.300	0.000	0.291	0.000		
CUSDEM	0.268	0.027	0.251	0.045	0.243	0.053	0.246	0.050	0.238	0.057		
CONSUP	-0.030	0.780	-0.004	0.973	-0.035	0.750	-0.037	0.731	-0.015	0.889		
SCITECH	-0.044	0.577	-0.025	0.744	-0.049	0.527	-0.047	0.543	-0.049	0.525		
Observations	511		511		511		511		511		511	
Censored obs.	167		167		167		167		167		167	
α	1.027		1.025		1.021		1.028		1.025		0.991	
Log-L	-784.123		-787.157		-784.180		-782.802		-784.211		-798.221	
LR [χ^2]*	53.944	0.000	47.876	0.000	53.830	0.000	56.586	0.000	53.768	0.000	25.748	0.001

* The degrees of freedom vary depending on the number of dropped variables.

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The determinants of commercialisation and break-even times of innovations

Abstract

Successful innovation is typically defined at the firm level where market shares, productivity, or profitability is taken as an indicator of success. Nonetheless, firms are simultaneously involved in many innovation development projects with varying success. This paper defines the success of innovations through the time taken for the innovations to reach commercialisation and the point of break-even, to investigate the relationships between the sources and success of innovations. The paper uses a database of Finnish innovations commercialised during the 1980s and 1990s, and contributes to previous research by covering a range of different types of innovations from various industries, and by applying econometric duration analysis. The results carry implications for the management of innovation and the design of policy from the viewpoint of trade-offs between the timeliness, objective and outcomes of innovation.

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VTT PUBLICATIONS 486 Successful innovation. The determinants of commercialisation and break-even times of innovations

This publication defines the success of innovations through the time taken for innovations to reach commercialisation and the point of break-even, to investigate the relationships between the sources and success of innovations. The publication uses a database of Finnish innovations, and contributes to previous research by covering a range of different types of innovations from various industries, and by applying econometric duration analysis.

The results indicate that commercialisation and break-even times are surprisingly short. Complex innovations are associated with longer commercialisation times, while exported innovations are associated with shorter break-even times. Different sources of innovation appear to have greater effects on the durations than firm size and the origin of innovations in specific sectors. Innovations related to customer demand and market niche shorten both commercialisation and break-even times, while science-based innovations prolong them. An interesting result is also that competitive markets shorten the break-even times of innovations.

The results carry implications for the management of innovation and the design of policy from the viewpoint of trade-offs between the timeliness, objectives and outcomes of innovation.

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