High Technology Commercialisation:

A Real Option Approach

A thesis submitted for the degree of Doctor of Philosophy

by

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List of Abbreviations

AUTM	Association of university technology managers
DCF	Discounted cash flow
IPO	Initial public offering
IP	Intellectual property
IPR	Intellectual property rights
MPS	Max Planck Society
NPL	Non patent literature
NPV	Net present value
NTBF	New technology based firm
PRO	Public research organization
ROT	Real option theory
TTO	Technology transfer office
UNICO	University companies association
USO	University spinout

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To my family, for their love

Abstract

The impact of uncertainty in the commercialization lifecycle of new technologies is a complex phenomenon. Technologies are research intensive and exposed to uncertainty regarding their successful development and functionality. Further these technologies have to be absorbed by volatile markets in order to be commercialized. These different forms of uncertainty are of primary importance for decision makers but have not been thoroughly studied in previous technology commercialization research and put under one theoretical framework. The main focus of this thesis is to comprehend the recently growing trend among universities and public research organizations to commercialize their research activities from an empirical and theoretical perspective. More particularly the thesis focuses on the life cycle of two main commercialization streams namely the entry and exit of university spinouts, which are companies that evolve from intellectual property developed within academic institutions as well as the licensing and licensing termination of inventions. The main focus of the thesis therefore analyses market and technological uncertainty and explains the conditions under which spinout formation, spinout failure, licensing and licensing failure occur by putting them under the theoretical framework of real option theory.

1 Introduction

What do Google and an MP3 player have in common? Both are based on innovations that originated from a university or public research institution. Google began in early 1996 as a research project by two PhD students at Stanford University in the USA whereas MP3 is a digital audio encoding format developed at the Fraunhofer Institute, which together with the Max Planck Society forms the top two public research institutions in Germany. In the last decade major research universities and public research organizations have undergone a tectonic shift from 'knowledge production' to 'capitalisation of knowledge'. This commercial orientation and increasing commercialisation activities among universities had implications not only for the university's financial advantage but had a great impact of improving regional or national economic performance (Etzkowitz et al., 2000). Commercial successes like the previously mentioned Google, the MP3 technology and many others have created a fertile ground for the seeds of commercial activities from public research organizations such as technology licensing and university spinouts[1]. The rising number of universities involved in commercial activities has been well documented in several surveys. The University Companies Association (UNICO, 2001) survey for the UK and the Association of University Technology Managers (AUTM) survey for the US (AUTM, 2002) showed that academic institutions are creating spinouts and commercializ-

[1] Spinouts are defined as new firms created to exploit commercially some knowledge, technology or research results developed within a university

ing their technologies at an increasing rate and reported that the number almost doubled in the last decade. Especially the growth of spinout activity has inspired a recent increase of research interest in this phenomenon (Djokovic and Vangelis, 2008).

Public research organizations as well as universities are entirely active in the high technology domain which is underlying very high risks in terms of technological development and completion as well as the market adaptation. We refer to the first risk as *technological uncertainty* which represents the uncertainty about the success and feasibility of the developed technology and the uncertainty if the underlying technology will satisfy quality, performance and standards that were initially intended (Dixit and Pindyck, 1994). The second risk that innovations in the high technology domain are exposed to is the commercial risk which represents the volatility of current market and demand structures. We refer to this form of risk as *market uncertainty*. The question how these forms of uncertainty impact the technology lifecycle has been recognized by research scholars but was not put under a theoretical framework or tested empirically (Shane, 2004b). Especially research on real options has contributed to our understanding of entry timing of investments (Miller and Folta, 2002) and has encouraged experimentation and the proactive exploration of uncertainty (McGrath, 1999). Therefore, we will extend real option theory to technology commercialization decisions by taking the perspective that uncertainty influences the value of the technology option as well as its investment timing.

The aim of this research will be to explore how different conditions of uncertainty, predominantly to be found in early stage technologies, affect the lifecycle of a high technology innovation.

In particular, we will examine the effects of external (market) and internal (technology) uncertainty on commercialization activity, as well as the timing of innovation commercialization. The elaboration of hypothesis will be grounded on the foundations of real option theory (ROT) in order to consolidate uncertainty and timing into a theoretical framework.

Our study includes data on all inventions created in the period from 1990 to 2003 by the top German Research Institution, Max Planck Society (MPS). It is therefore the first study to use non-US data to directly analyse technology commercialization in form of spinout and licensing activity. The information where, when and in what form patents are licensed or spun out was directly obtained from the university technology transfer offices. Since we are looking at the occurrence of events like the occurrence of a spinout or the licensing of a patent and our dataset contains censored and time dependent covariates, we will use Cox regression time dependent analysis throughout the study as the primary statistical modelling approach. This gives us the possibility to predict the likelihood of new firm formation, licensing initiation or licensing termination per patent-year on the basis of several time dependent covariates that are used in our study.

The thesis proceeds as follows. In the next chapter we will focus on the phenomenon of university commercialization activities with a focus on university spinouts by giving a comprehensive overview of the factors influencing commercialization and spinout activity recent research has identified. Still we lack comprehensive studies, which critically review this literature as well as its theoretical contributions. Chapter two aims to fill this knowledge gap.

Chapter three will introduce real option theory and explain its applicability to the commercialization phenomenon and chapter four will provide an overview of using patents as measurement concepts to provide the setting for chapters five and six. Chapter five will elaborate the effects of the different concepts of uncertainty on spinout activity. The effects of uncertainty on innovation licensing and licensing termination will be analysed in chapter six giving a complete overview of the affects of uncertainty on the different commercial outcomes of an innovation thereby comprehending the analysis of the commercialization lifecycle.

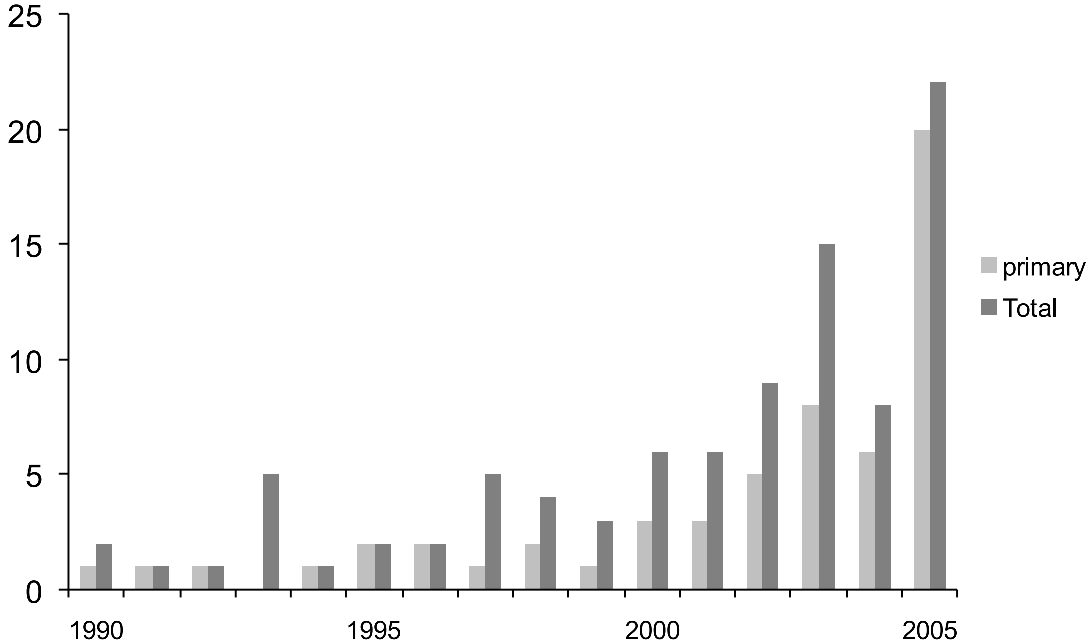
2 Spinouts from academic institutions: A literature review with suggestions for further research

2.1 Introduction

University spinouts constitute a complex phenomenon within the entrepreneurship research field. They are companies which evolve from universities through commercialisation of intellectual property and transfer of technology developed within academic institutions (Birley, 2002). Despite their importance as possible sources of wealth creation and job opportunities in the economy (Steffenson et al., 2000), researchers started to focus explicitly on university spinouts only recently.

The changing role of universities towards commercialisation activities combined with governmental and institutional support mechanisms is creating a fertile ground for the seeds of university spinouts. The rising number of universities involved in commercialisation activities such as licensing and spinning out has been well reported and documented in several surveys. The University Companies Association (UNICO, 2001) survey in the UK and the AUTM survey in the US (AUTM, 2002) showed that academic institutions are creating company spinouts at an increasing rate. In the US the annual number of spinouts increased from 202 in 1996 to 424 in 2001. In the UK a sharp rise of spinout creation between 1996 and 2001 has also been reported from an average of 94.8 per year in the four years up to the end of 2000 to the 175 created in 2001. The number of patents and licenses in the last decade almost tripled whereas the start-up activity among universities almost doubled (AUTM, 2002). This growth of spinout activities has inspired a recent increase of research interest on the phenomenon (see Figure 2-1). Still we lack comprehensive studies, which critically review the literature and its theoretical contributions. Our paper aims to fill this knowledge gap.

Figure 2-1: Evolution of primary and secondary spinout literature



Our literature review is mainly based on papers published in core management journals, which we identified systematically using the ABI/INFORM, Business Source Premier and Science Direct databases. The paper is structured as follows. We first provide an overview of existing definitions of spinouts followed by a brief review of process studies, to help the reader ‘relate’ to the phenomenon. We then present the methodology followed to identify the papers, categorise the core body of the literature and provide a comprehensive review of its main themes. We conclude with our views about the current gaps in the literature and directions for further enquiry.

2.2 Spinout definition and process

What is a university spinout organisation (USO)? We believe that the definition of a USO should specify the 'outcome' of the spinout process, the essential 'parties' involved in it, and the 'core elements' that are transferred (spun-out) during that process.

The *outcome* of a USO is firm formation and all current definitions are unanimous in this respect (Carayannis et al., 1998; Clarysse et al., 2000; Klofsten and Dylan, 2000). Regarding the *involved parties* Roberts and Malone (1996) identified the following four: (1) the parent organisation from which the technology is extracted, (2) the technology originator, i.e. the person who brings the technology from a basic research stage to a point at which technology transfer can begin, (3) the entrepreneur who attempts to create a new venture centred on the technology, and (4) the venture investor that provides funding for the new company.

The *core elements* transferred to a USO are technology and/or people. Researchers produced various definitions of spinouts depending on their approach to the above elements. 'Technology' can be interpreted in two ways: a) A formalised piece of intellectual property such as a group of patents; in this case a spinout is "a new company founded to exploit a piece of intellectual property within an academic institution" (AUTM, 2002, Di Gregorio & Shane, 2003) or b) some knowledge produced in a university, which does not necessarily have to be formalised; in this case "university spinouts are new firms created to exploit commercially some knowledge, technology or research results developed within a university" (Pirnay et al., 2003).

Regarding the transfer of 'people', Smilor et al. (1990) developed a narrow definition of a USO (similar to an early definition by McQueen & Wallmark, 1982) that excludes the possibility of the technology-only spinning out, without being accompanied by people from the parent organisation. To them a spinout is "a new company that is formed (1) by individuals who were former employees of a parent organisation and (2) is based on a core technology that is transferred from the parent organisation" (Smilor et al. 1990). Radosevich (1995) differentiated between inventor–entrepreneurs and surrogate–entrepreneurs who did not invent the technology but acquired the rights to commercialise it from the university. Nicolaou and Birley (2003a) 'broadened' Smilor's strict definition accepting as a necessary condition for a USO the transfer of a technology, but not necessarily of people from the parent organisation. According to them a USO includes: (1) the transfer of a core technology from an academic institution into a new company and (2) the founding member(s) may include the inventor academic(s) who may or may not be currently affiliated with the academic institution. For this paper we adopt the above spinout definition by Nicolaou and Birley (2003a) which considers technology transfer in form of a new company, but is inclusive of firms run by surrogate entrepreneurs without the involvement of the academic inventors.

A few studies focused on the process of university spinout formation and evolution (Ndonzuau et al., 2002; Vohora et al., 2004; Carayannis et al., 1998; Roberts and Malone, 1996), typically describing the process with a number of phases. Ndonzuau et al. (2002) identified four main phases of spinout creation: (1) business idea generation from research; (2) finalisation of new venture projects out of ideas; (3) launching spin-out firms from projects; (4) strengthening the creation of economic value. Beyond this, Vohora et al. (2004) offered an evolutionary perspective on the process of the spinout phenomenon focusing on the company itself. They identified four stages, which USO's undergo during their formation (1) research phase, (2) opportunity framing phase, (3) pre-organisation, (4) reorientation. The model of the study focused on the transition between the phases and identified four critical junctures with increasing complexity, which a USO must pass in order to progress to the next phase; (1) opportunity recognition, (2) entrepreneurial commitment, (3) threshold of credibility, (4) threshold of sustainability. In general, qualitative and longitudinal process studies on university spinouts are useful and welcome, as they explore the new phenomenon in detail, identify constructs, spot relationships and open avenues for further confirmatory quantitative work.

2.3 Methodology

We searched three major databases (ABI/INFORM, Business Source Premier and Science Direct) for specified keywords[2] since not all of the databases are

[2] The main keywords we have used to screen the articles were: universit* start*, universit* spin*, academic spin*, academic start*, academic start*, entrepreneur* universit*, universit* commercialization, universit* ntbf, academic* ntbf. The asterisk stands for finding all combinations of a word or word fragment. E.g. spin* finds spinouts as well as spinoffs.

covering the same journals. After each query we manually searched through the abstracts to pre-screen the relevant articles. Subsequently we reviewed the references of each relevant article in order to identify published material not archived in the databases. After filtering and evaluating the initial pool of more than 250 papers, we extracted 102 relevant ones that included spinouts in their findings. We categorised these 102 papers into two groups: ‘primary’ and ‘secondary’ spinout literature. The primary spinout literature included 60 papers, which deliberately and solely aimed to study the spinout phenomenon conceptually or empirically. Instead the 42 papers in the secondary literature did not exclusively focus on spinouts, but produced relevant findings through the study of wider phenomena, such as technology transfer and New Technology Based Firms (NTBF’s). Table 9-6 shows the number of primary and secondary spinout literature since 1990.

Table 2-1: Content analysis of primary and secondary spinout papers

gives aggregated descriptive statistics on the journals that the spinout literature appeared, the geographical location of the authors and the proportion of conceptual versus empirical pieces. We also grouped the papers into phenomenon-focused versus theory-driven; Phenomenon-focused studies either described aspects of the spinout phenomenon or explored relationships between constructs based on a practical/ empirical logic. Theory-driven studies instead explained hypothesised relationships or events utilising broader theoretical frameworks. The judgement of whether a study is theory-driven or not is often subjective and therefore the categorisation is indicative only, illustrating our own views (Table 2-1: Content analysis of primary and secondary spinout papers shows the results).

Table 2-1: Content analysis of primary and secondary spinout papers

Journals	primary literature	secondary literature
International Journal of Entr. & Inn. Management	3	1
International Journal of Technology Management	1	1
Journal of Business Venturing	9	2
Journal of Technology Transfer	6	3
Management Science	4	2
R&D Management	4	3
Research Policy	9	10
Small Business Economics	3	1
Technology Analysis & Strategic Management	-	2
Technovation	11	4
Others	10	13
Total	**60**	**42**

Authors		
Europe	62%	n/A
Other	7%	n/A
USA	31%	n/A

Studies	1980-2001	2002-2005
Phenomenon focused	95.2%	51.3%
Theory-driven	4.8%	48.7%
Empirical	85.7%	71.8%
Conceptual	14.3%	28.2%
Qualitative	38.9%	44.8%
Quantitative	61.1%	55.2%

We reviewed all the 103 papers listed in Table 9-6 in the Appendix. Our citation coding allows the reader to quickly identify whether a paper belongs to the primary or the secondary literature, whether it is conceptual or empirical and whether it is phenomenon-focused or theory-driven. Apart from the key papers on spinouts, this review draws from a wider spectrum of related studies in the management field, in order to highlight theoretical contributions of the current literature and to propose areas for further research.

We a priori categorised the literature into three clusters according to the level of analysis, namely, macro, meso and micro level. Macro level studies focused on the macroeconomic environment of spinouts and analysed the role of the *government and industry* in the spinout process. In this level of analysis, researchers looked at spinout related policies and support mechanisms, the impact of spinouts on the regional economy as well as favourable conditions of the industry and market environment. Meso-level studies focused on the *university* and the *Technology Transfer Office (TTO)*. Studies tried to identify the support mechanisms that can be employed by the academic institution to incentivise spinout creation, as well as to explore the effectiveness of spinning out as a university technology transfer mechanism. Micro-level studies focused on the *firms and the individual entrepreneurs* and looked at networks of spinouts and their founders as well as human relations and interactions during the spinout formation process.

2.4 Macro Level studies

2.4.1 Governmental and industrial support mechanisms

Some academics and economists voiced concerns that the exploitation of academic knowledge will jeopardise the basic role of the university (Mazzoleni and Nelson, 1998; Lee, 1996; Rogers, 1986), that encouraging commercialisation will alter the institutional rules and conventions under which research takes place

(Dasgupta and David, 1994) and that spinouts have very little impact on the local or regional development of the economy (Harmon, et al. 1997). Others (currently the dominant view) have positive attitudes towards university commercialisation activities and believe that the economic development momentum that has been generated at institutions in recent years should be vigorously pursued in a proactive manner (Chrisman et al., 1995). A body of research *documented how governments and the industry support and incentivise the creation of new ventures from public research institutions.*

Prior to 1980, the incentive structures for academics and universities induced by government were not well developed and few universities were engaged in technology licensing and active commercialisation (Shane, 2002a). Recognising the value of university commercialisation activities for national wealth creation, several governments shifted their technology policy from a 'market failure' paradigm (which assumes that innovation flows from and to private sector with minimal university or governmental role) to a 'cooperative technology paradigm' (which assumes that governmental laboratories and universities can play a role in developing technology) (see Bozeman, 2000 for a review of policy models in the USA and Rothwell and Dogson, 1992 for a description of European technology policy models).

Besides major policy changes (such as the Bayh Dole Act), other supporting policies were created in the US, such as promoting cooperative R&D, patent policy to expand government technology, relaxing anti-trust regulations, developing cooperative research centres and altering guidelines for disposition of government owned intellectual property (Bozeman, 2000). Moreover, governments developed support mechanisms of financial nature in the form of grants and public funding. The First Action Plan for Innovation funded the start-up and growth of technology-based enterprises, especially spin-outs (Klofsten and Dylan, 2000). Grants in the USA like the Small Business Innovation Research and the Small Business Technology Transfer Research, fund high-risk R&D with commercial potential (Meyer, 2003), enabling scientists-founders to overcome financial barriers. In the same way, the U.K. legislation has provided stimuli for the commercialization of university-based research with programs such as the University Challenge, Science Enterprise Challenge, and the Higher Education Innovation Fund (Lockett et al., 2005).

Apart from describing the government support mechanisms, some studies attempted to *evaluate the effectiveness of governmental technology transfer policy.* Recent findings showed that the Bayh-Dole Act led universities to concentrate their patenting in lines of business in which licensing is more effective (Shane, 2004a). Since patents precede university commercialisation activities in general (which include not only licensing but also spinning out), one could intuitively propose that intellectual property policies such as the Bayh Dole act would also be indirectly correlated with spinout creation. Defining and most importantly proving empirically these relationships between government policies, patent direction and spinout creation is an avenue for future research. Goldfarb and Henrekson (2003) published an interesting study towards this direction linking Sweden's poor record on spinout creation, with the country's policies, which has largely ignored the importance of setting-up incentives for universities and academics to pursue commercialisation of technology.

The industry can stimulate the spinout phenomenon by actively engaging in university industry collaboration. The collaboration activities can range from joint R&D projects with spinout companies or universities, technology consulting and contract research to technology purchases (Motohashi, 2005). Furthermore, the industry can support spinouts by developing well functioning financial markets, like the NASDAQ and NASDAQ Europe, which are essential for high technology entrepreneurship (Van Looy et al., 2003). They provide venture capitalists with incentives to invest in early stage technologies and to initial public offering (IPO) their spinout 'babies' with immense capital gains. In addition, the importance of a well-established local industry which can provide suppliers, partners and buyers to young spin-out companies is also well-documented in the strategy literature (Porter, 1990).

2.4.2 Technology and Market driven commercialisation

This research stream focused on explaining *which inventions will be successfully commercialised by firm formation*, looking at the technology and market factors that are beneficial to spin-out creation. Shane (2001a) attempted to reconcile earlier contradictory findings, and proposed that the tendency for an invention to be exploited through firm creation varies with the attributes of the technology regime (the age of the technical field, the tendency of the market toward segmentation, the effectiveness of patents, and the importance of complementary assets), testing his framework empirically. Lowe (1993) also provided a conceptual framework of favourable market preconditions for technology transfer mechanisms in general, by revealing spinout companies are most likely to form when complementary assets are of high availability to university and/or inventor and the technology used is under strong legal and technical protection. Further, Lowe stated that spinouts are more likely to appear in emerging industries where technological trajectories are still evolving and where innovation is radical. Empirical evidence on this framework is still missing. Generally, we believe that there is scope for more empirical work that systematically consolidates, puts order and tests the predictions of current conceptual frameworks.

2.5 Meso Level studies

2.5.1 University support mechanisms

The changing role of universities from 'knowledge production' to 'capitalisation of knowledge' with the objective of improving regional or national economic performance as well as the university's financial advantage and that of its faculty (Etzkowitz et al., 2000) led to increasing commercialisation activities among universities in the last two decades. Many universities introduced technology incubators (see Mian, 1997, Link and Scott, 2005), science and technology parks (usually larger, often government-funded developments to accommodate local NTBF's in general and not only spinouts) and subsidy programs (Shane, 2002b). Of 52 UK universities in 1987, 34 had formal science parks (Monck et al. 1988). Cooper (1984) argued that incubators affect the spinout rate and the patterns of success of newly found ventures by mentoring them and by providing human capital support. However, the evaluative literature on science and technology parks is neither conclusive on their effectiveness (see MacDonald, 1987; Miller and Cote, 1987; Massey et al., 1992, Di Gregorio and Shane, 2003) nor on a framework for their systematic understanding (Phan et al., 2005).

Another emerging support vehicle of spinout creation is the Technology Transfer Office (TTO) operated by universities. TTO's play an active role in commercializing university research by identifying, protecting, marketing and licensing intellectual property developed by faculty. Studies that analysed systematically the productivity impact of TTO's focused more on the effectiveness of technological diffusion through licensing rather than spinning out (Siegel et al., 2003). Spinout related studies focusing on the TTO appeared only recently by Lockett and Wright (2005) and Powers and McDougall (2005) who found that the size and experience of a technology transfer office has positive influence on spinout activity.

2.5.2 University based determinants of spinout activity

Besides tangible organisational units such as incubators and TTO's, universities can offer a supportive organisational culture towards entrepreneurship. Henrekson and Rosenberg (2001) found that pertinent incentive structures that promote entrepreneurial culture can explain why an overall flourishing economy like Sweden has modest success with academic entrepreneurship.

Recent studies debated *which university related determinants of spinout activity can explain inter-university variation of spinout creation*. Lockett and Wright (2005) examined the determinants of spinout formation under the lens of the knowledge based view of the firm and found that the business development capabilities of technology transfer offices and the royalty regime of the universities are positively associated with spinout formation. Feldman et al. (2002) found that the university's use of equity is positively correlated to prior experience with technology transfer, to success in relation to other institutions, and to structural characteristics related to the type of university. Recent studies used the resource based view to give further evidence that the resource stock of universities and the combination of resources are highly important to explain inter-university variations of spinout activity (Link and Scott, 2005, O'Shea et al, 2005).

It is important to keep in mind that the spinout phenomenon is relatively new for the majority of the universities especially in Europe (institutions such as MIT and Stanford which have tradition and experience in spinning out technology companies are the exceptions rather than the rule). Therefore, universities are currently experimenting, creating rules and procedures and (hopefully) learning from practice (Birley, 2002 gives an experience-based account of the issues faced at Imperial College London).

2.5.3 Effectiveness of spinning out as a university technology transfer mechanism

Rogers et al. (2001) identified 5 different technology transfer mechanisms from universities (spin-offs, licensing, meetings, publications, and cooperative R&D agreements) out of which technology licensing and spinning out of ventures were the ones with the highest commercialisation value. A stream of research examined *favourable conditions for universities to commercialise technology in form of USO's as opposed to licensing.*

Universities have traditionally exhibited great reluctance to take equity positions in spin-off firms (Brown, 1985). Shane (2002a) suggested that university inventors become entrepreneurs because of the failures in the market of knowledge, suggesting that "inventor entrepreneurship is a second-best solution to the commercialisation of new technology". However, agreements in which a university takes equity position in a company in exchange for providing the right to use university intellectual property is becoming an emerging mechanism and the focus of interest of many universities (Feldman et al., 2002). Jensen and Thursby (2001) argued that equity investments not only provide the same development incentives as royalties (because both are based on output sales) but also generate greater revenue. This is consistent with the study by Bray and Lee (2000) who found that spinning-out is a far more effective technology transfer mechanism compared to licensing, as it creates a 10 times higher income, and therefore argued that license positions are only taken when "technology is not suitable for a spin-off company". An interesting insight into the decision making process of commercializing an invention in form of a licensing agreement or spinout was provided by Druilhe and Garnsey (2004). Using a case based methodology they showed that the business models of commercialization can be altered from licensing to spinning out and vice versa as academic entrepreneurs improve their knowledge of resources and opportunities.

2.6 Micro Level studies

2.6.1 Role of founders and founding team

Nicolaou and Birley (2003a) proposed a trichotomous categorization of university spinouts based on the founder role of academics, namely technological, hybrid and orthodox spinouts. An orthodox spinout involves both the academic inventor(s) and the technology spinning out from the institution, a hybrid spinout involves the technology spinning out and the academic(s) retaining his or her university position, but holding a position within the company, and a technology spinout involves the technology spinning out but the academic maintaining no connection with the newly established firm.

The literature generally debated *the effect of the involvement and role of academic and/or surrogate entrepreneurs on the performance of spinouts.* Doutriaux (1987) and Roberts (1991a) reported that many spinouts start on a part-time basis (the academics keep their position at the university and "moonlight" into the new firm) and questioned their success. In an early study, Olofson and Wahlbin (1984) linked academic exodus with growth, finding that spinouts with the highest growth rates were the ones involving academics who left the university. The advantage of keeping the academics involved in the spinout process and close to the new venture can be due to the increasing effectiveness of the technology transfer achieved (Roberts and Hauptman, 1986).

Clarysse and Moray (2004) offered another view on the role of human capital in spinout creation, illustrating the possibility that the academic founder and his team evolve and learn over time during their entrepreneurial involvement. The study suggests that instead of hiring a CEO at the start-up of the company, it might be a more efficient choice to ''coach'' the start-up team and give them the time and freedom to learn (Clarysse and Moray, 2004). External shocks such as a capital increase restructure the organisation at a later stage. The study highlights further problems of involving surrogate entrepreneurs, including their high turnover, their problems in accepting the academics as well as their lack of technical understanding (Clarysse and Moray, 2004).

So do surrogate entrepreneurs contribute to the success and performance of university spinouts and are academics (who are perceived to have limited business knowledge and industrial experience) suitable entrepreneurs? Researchers have argued differently in addressing this question, based on their dissimilar findings. Druilhe and Garnsey (2004) e.g. concluded that spin-out companies in practice are highly variable scenarios and defy any formulaic approach. In general, the literature indicated that spinning out from academia is a complex phenomenon, because of the number and diversity of human parties involved (academic and surrogate entrepreneurs, research students, research sponsors, lab and department heads, TTO professionals, members and heads of university equity committees, university-nominated directors, investors) and of the conflicts of interest that arise as a result of their interdependence (Birley, 2002).

2.6.2 Networks with University and Industry

Networks can facilitate the emergence of ventures by providing four substantial benefits namely, augmenting the opportunity identification process, providing access to loci of resources, engendering timing advantages, and constituting a source of trust (Nicolaou and Birley, 2003a). During their pre- and post-formation stages, spinouts and their founders are involved in networks with two different entities, namely their parent organisation (university) and the industry (industry partners, investors, contractors etc.). Recognising the importance of networking in the spinout phenomenon, researchers explored the effect of networks on spinouts structure and performance.

2.6.2.1 Networks with the university

Keeping post-formation links with the parent institution, can provide spinouts with tangible resources such as laboratory facilities and access to research equipment (Steffenson et al., 2000) as well as intangible resources such as access to human capital and scientific and business knowledge (Rappert et al., 1999). *Research focused on the characteristics as well as on the effects of ties between universities and spinout companies.* It was found that the proximity to parent institutions had beneficial effect on spinout performance after the spinout formation (Roberts, 1991a, Lindelöf and Löfsten, 2004), and that the network relations between USO and universities are based on small number of strong ties to universities, with a high degree of trust and informality (Johansson et al., 2005). In contrast, Lee et al. (2001) examined external networks of technology start-ups (not spinouts from academic institutions) and found that only networks to venture capital investors predicted start-up performance. Rappert et al. (1999) confirmed that due to their origins, university spinouts had a wider range of contacts and attached a greater importance to formal and informal contacts in universities than similar start-ups formed independently of universities.

Perez and Sanchez (2003) focused on the evolutionary aspect of spinout networks, stressing that networking towards the university decreased after their early years, with a shift of focus towards networking with customers.

2.6.2.2 Networks with industry

Interaction with industry is essential in order to gather relevant information about the new business, to find external support and services, to access external resources not available in-house, to promote the new company, and to look for business advice (Birley, 1985). As a result inter-industrial networks can have positive impact, cultivating new venture success and growth (Van de Ven, 1984). University spinouts are networking with several industrial parties during their pre and post start-up phase like venture capital investors, partners, competitors, and customers.

Grandi and Grimaldi (2003) investigated academic founding teams, their intention to set up relations with industrial partners and the frequency of their interactions. They found that when certain articulation of roles emerges in teams and when they are incomplete, they are more likely to interact with external agents. Further, founders of spinouts will interact (even increasingly) after spinout formation with their own ties of personal networks (Grandi and Grimaldi, 2003), which makes social capital endowments of founders in pre-formation stages crucial.

Nicolaou and Birley (2003b) found a link between pre-formation networking (the academics' embeddedness in a network of endoinstitutional and exoinstitutional ties) and the spinout structure (orthodox, technology or hybrid spinout). They then suggested that the structure of a spinout, depending on the ties the academic founders, could influence its growth trajectories (i.e. performance). This logic (networks affect structure which affects performance) requires further empirical testing.

Shane and Stuart (2002) offered empirical evidence of the network-performance relationship, analysing how social capital endowments of the founders affect the likelihood of three critical outcomes of spinouts: attracting venture capital financing, experiencing IPO's and fail. Direct and indirect linkages to investors were found to be constructive to receiving venture funding and reduced the likelihood of spinout failure. Receiving venture funding was the single most important determinant for the spinout to experience an IPO. Therefore, personal networks of founders had a long-term positive effect on spinout performance. Lockett et al. (2003) confirmed the importance of networks, at the level of the university (meso level). In a study measuring perceptions of TTO's, they found that more successful universities had generally a stronger working relationship with venture capital investors and possessed greater amount of networks to the industry.

2.6.2.3 Performance of USO's

Although spinout performance has been researched sporadically in the past partly because of the relative newness of the spinout phenomenon, recent studies are increasingly researching this aspect. Performance has been studied under a multi dimensional framework including the analysis of survival rates, profitability and growth rates. It is well documented that failure rates of USO's are well below the national average in the USA and European countries (Degroof and Roberts, 2004; AUTM, 2002; UNICO, 2001). Still it is inconclusive if the higher survival rates of spinouts can be attributed to higher fitness of USO's or rather to support systems of their parent organization that are keeping them 'alive'; Rothaermel and Thursby (2005) found that spinouts with strong ties to their parent organizations were less likely to fail but also less likely to successfully graduate within a timely manner. Moreover, in a comparison between new technology-based ventures and university spinouts Ensley and Hmieleski (2005) showed that spinouts were not necessarily better performers. They showed that the latter were significantly lower performing in terms of cash flow and revenue growth and that their top management teams were less dynamic and more homogenous. These findings show that survival rates might not be ideal measures of spinout performance and that support mechanisms can as well be counter-productive. Future research should disentangle these findings and explain under what circumstances support mechanisms of parent institutions can be beneficial versus detrimental.

Further studies that focused on the determinants of spinout performance looked at the policy setting of universities and TTO's and found that policies can have increasing effect on the potential growth of ventures (Degroof and Roberts, 2004). Moreover, it was found that linkages to different actors, such as clients, research labs, parent university and particularly investors are important determinants of success and performance (Mustar, 1997, Shane and Stuart, 2002).

2.7 Directions for further research

We illustrated that the spinout literature is vibrant and the recent increase in the number of studies can prove that. Although a number of scholars postulated that the literature on spinouts has been mainly accumulative and atheoretical (e.g. Autio, 2000), we see recently a positive trend towards theory-driven studies (they increasing from 5% to 49% in the past four years). We showed that the phenomenon was studied from different points of view and units of analysis (government level, university level and firm/individual level). To give a structured picture of a rather diverse literature we organised the studies under three broad headings (macro- meso- and micro- level studies).

We observed a strong increase recently in primary spinout literature which shows that the spinout phenomenon is becoming more mature. As spinout life cycles are becoming more transparent, we expect further studies to focus more on performance and untangle if and where differences exist between spinouts and independent new technology based companies. This is especially important since it defines the legitimacy to study spinouts as a phenomenon on its own. Moreover, we think that there is scope for further research on the post-formation product development and growth of spinout companies. How do spin-outs develop commercial products from an initial technology, with their limited resources? Roberts (1991b) illustrated the importance of product development (in contrast with research work) as source of the founding technology. The new product development literature focused more on established firms and not on young technology companies (Krishnan and Ulrich, 2001). The broader literature on growth of new technology based firms is a good starting point (for a review see Autio, 2000) as well as the literature on technology alliances (it is very common for spinouts to look for industrial partners in order to co-develop their technology).

We believe that the evaluation of spinning out as a commercialization strategy of universities and their TTO's deserves further research attention in the future. Bozeman (2000) summarised results of the wider technology transfer literature and developed a 5-dimensional taxonomy of the reasons for technology transfer, which inspires some important but yet unanswered research questions related with the university-driven commercialisation stream. What is the measure of success for the university TTO's? Are universities focusing on 'quality' spinouts that have significant potential for success and financial gain? Or is quantity their target, i.e. a high 'spinout rate', aiming to increase their perceived reputation, attract government funding and justify the expense for their TTO's? This 'quantity versus quality' question should trigger a more in-depth theory-driven exploration of the institutional structure and strategic objectives of Universities and their TTO's and also of the career path and reward structure of the new breed of technology transfer professionals. This is a good direction for future research (especially as the phenomenon matures) aiming to identify the characteristics of universities and TTO's capable of spinning out 'successful' firms.

We believe that a very conducive route for further research is to untangle what an entrepreneurial culture within the university exactly means, how it is achieved and what effect it has on the spinout creation. From a theoretical point of view, we suggest a link of the university spinout process with the literature on organisational culture. Moreover, we propose that future studies should systematically evaluate the impact of entrepreneurship programmes, business plan competitions, networking events, and incentive / reward structures. From a theoretical angle it would be interesting to link such activities with knowledge theory (what exactly, if any, do technical academics learn?) Also studies should investigate the effect of the above entrepreneurship related activities on the academics' entrepreneurial intention and subsequent action.

We argue further that there is scope for theory-driven research on the power-relationships between the various stakeholders and their effect on the spinout process and outcome. For example, one of the most frustrating events for spinout teams is the equity split between the university, the entrepreneur, the team of inventors (each one contributing in some way to the invention) and (often at a later stage) the investor. What drives the equity split? Apart from negotiating skills, we propose that the role of the involved individuals within the academic institution (i.e. their 'day job') and their power-dependence is crucial for the outcome. Dependency relationships might influence various other decisions regarding university spinouts, such as whether the academic leaves or stays in the university, the selection of the people who act as technical consultants and university-nominated directors and the use of university resources (such as labs) by the new company. Further research is required to define more clearly and prove empirically such arguments.

Another interesting area for further enquiry is to explore the interaction between networks and other potential determinants of spinout structure and performance, such as the personal values and behaviour of the academic entrepreneurs. Currently, the literature on networks in spinout research seems to treat networking somehow independently from other factors determining the spinout process. An interesting research question is how networks come into existence, what fosters them and how they influence success and performance of spinouts. In a recent review of the network literature in entrepreneurship Hoang and Antoncic (2003) called for more process, longitudinal research, with network constructs as the 'dependent' variable.

Furthermore, there is scope for focusing on the academic entrepreneurs as the unit of analysis, linking the spinout phenomenon with entrepreneurship theory on opportunity identification (for the construct and theory of opportunity see Shane and Venkataraman, 2000; Ardichvili et al. 2003). It would be interesting to investigate how technological opportunities are actually identified within an academic environment and why some scientists do identify them and decide to pursue them while others do not.

We claim that the complexity of the spinout phenomenon due to the different parties, relationships and processes involved makes it an ideal context for testing and extending theory and that there is plenty of scope for further work to untangle and understand it thoroughly. We agree with Locket et al (2005) that multi-level studies are required to increase the understanding of the spin-out phenomenon. Overall, we propose that the key for future work is to ask the most interesting and practical phenomenon-specific questions but then tackle them with the most theoretical explanations.

Spinning out from academic institutions is currently a booming phenomenon, which will probably attract increasing research attention in the coming years. In this paper we have reviewed and organised the existing spinout literature, to achieve a double aim a) to help newcomers into this exciting field to identify what we already know and b) to offer fresh ideas for future research directions.

3 Real option theory

Real option theory is derived from the financial option modelling including Nobel Prize winning option models of Black-Scholes (1973). In contrast to their financial counterparts, real options represent investments in (nonfinancial) assets with an uncertain payoff that convey the right, but not the obligation, to exercise the investment, should the total payoff look attractive (Damodaran, 2001).

Options are protected against downside risk, since the expiration of the option without exercising can only lead to the loss of the right (option premium) rather than the whole investment itself. Conversely, ordinary financial options are detailed in the contract and its parameters known, whereas characteristics of real options must be identified and specified (Amram and Kulatilaka, 1999). The underlying asset for a financial option is a publicly traded security and is easily observable. With real options, the underlying asset is not publicly traded and has to be calculated.

3.1 Competing Theories

Firm entry and licensing has traditionally been discussed from several theoretical perspectives. The main being addressed in literature are behavioural, resource based, transaction cost theory and the neoclassical investment theory. Other forms of governance structures such as licensing were discussed under these theoretical frameworks but not in a rigorous manner (Ziedonis, 2007).

It was shown by Busenitz and Barney (1997) that entrepreneurs can be subject to cognitive biases when setting up a new firm. Further personal desire to become an entrepreneur will contribute to that fact (Evans and Leighton, 1989).

Access to suitable resources and the costs of those resources (including opportunity cost) are heavily influencing the firm formation decision. Capital availability (Acs and Audretsch, 1989), stronger social ties and networks (Aldrich and Zimmer, 1986) and prior experience (Cooper et al., 1989) have been shown to be important factors that influence the exploitation entrepreneurial opportunities.

The transaction cost economic approach within the theory of the firm (Williamson 1985, Williamson 1991) has been used traditionally to address uncertainty and the entry decision. Therefore both real options theory and transaction cost economics deal with similar issues in respect to the firm formation but with important differences which will be discussed in more detail. Transaction cost economics (TCE) identifies the most transaction cost efficient form of coordination between sellers and buyers and defines which forms of coordination (such as markets, hierarchies or hybrid forms of coordination) is most likely to occur. TCE moves away from the strong form of rationality and assumes bounded rationality and that cognitive constraints limit human behavior. However, individuals try to maximize their utility within their cognitive constraints (Williamson 1985) while being risk-neutral.

At the center of transaction cost economics is asset specificity which illuminates that an investment made to support a particular transaction can have a higher value to that transaction than they would have if they were redeployed for any other purpose. More precisely, given the attribute of asset specificity, TCE analyzes which form of coordination is most appropriate to minimize transaction costs and subsequently which form of structure will be chosen to govern the transaction. According to TCE, the transaction cost minimizing governance structures should be chosen to protect the partners against behavioral.

At first glance it can be seen that real option theory and transaction cost theory show several parallels. Both approaches address the important influence of sequential decision making under uncertainty. In contrast to that both approaches differ in their assumptions on rationality of the agents involved. On one hand TCE assumes bounded rationality whereas ROT uses an unbounded rationality perspective. In the second perspective, there is no necessity to organize the transaction within the firm. Moreover, both approaches focus on different origins of uncertainty. While TCE concentrates on the governance structure to reduce behavioral uncertainty, the real options approach mainly focuses on environmental (exogenous) types of uncertainty. Further ROT can include technological (endogenous) uncertainty in its theoretical framework which will be discussed in more detail in this thesis. Since both approaches deal with different types of uncertainty affecting economic organization, the real option approach can expand understanding on the types of uncertainty the TCE theory does not focus on (i.e. environmental and technological uncertainty).

Another theoretical angle to look at the different governance structures discussed in this thesis is the neoclassical investment theory which focuses on the new present value (NPV) of an investment and estimates the value of a project by taking its expected value of future cash flows and discounts them at the risk-free rate to the present. According to this neoclassical perspective, managers should enter when the NPV is above zero or exit when the remaining value falls below zero. The NPV approach assumes no flexibility in decision making and does not account for any optionality in the decision making process of the investor. It calculates the value of the investment considering that the investment is totally reversible (Dixit and Pindyck, 1994) meaning that the investment can be totally recovered if it turns out to be worse than anticipated. If e.g. the firm is able to recover all costs from an investment, there is no advantage of delaying an investment. Further, if the investment were unsuccessful, the firm would simply discontinue development and recoup its investment. An important feature of real options is therefore that the underlying investment is irreversible, which is true for most real life investments. The ability to delay an irreversible investment can affect the value of the investment and subsequently the decision to invest (Dixit and Pindyck, 1994). Therefore NPV calculations that fail to recognize the value of options will systematically undervalue investment opportunities. In traditional settings NPV analysis is applicable especially in situations where the analysis returns a large and positive net present value and the results do not necessarily require any further validation. Furthermore when there are no large uncertainties regarding the underlying investment, NPV analysis is an acceptable approach. On the other hand real options analysis can more accurately assess the nature of an investment if large uncertainties are present, the future growth of the investment is a significant source of investment value and when sequential investments are possible.

The power of real option theory compared to the neoclassical investment theory therefore lies in the understanding of the effects of uncertainty and incorporating it into a valuation framework where other standard valuation and strategic planning tools have limitations (Amram and Kulatilaka, 1999). It is important to grasp the key concept of option theory, irrespective if they are financial or real options. Option theory embraces uncertainty and sees it as a necessity that can enhance the value of options. It appreciates that uncertainty creates opportunities and options provide companies or managers with the right to act on them and each additional option that is embedded in an investment increases its value.

Therefore the reason for choosing the real option framework becomes evident from two main perspectives. The first one which is **output specific** enables us to put different events like firm formation, licensing, firm failure and licensing termination under one theoretical framework. These different outcomes previously needed to be explained by different theoretical frameworks. The exception is neoclassical investment theory which on the other hand lacks the importance of uncertainty on the investment entry/ exit decision in its discussion. This brings us to the second perspective which is **input specific**. We have shown that uncertainty has been put under a theoretical framework (i.e. behavioural uncertainty in TCE approach) but ROT is the framework that enables us to discuss exogenous and endogenous uncertainties and their respective effects at the same time.

3.2 Types of Real Options

Different types of real options have been identified in real investment problems and can be summarized as follows:

Option to defer or delay investment

Options to defer or delay usually exist when there is a value of waiting for some uncertain event to resolve before committing to an investment. The option captures the value of being able not to commit to an investment now but rather wait until uncertainty is resolved.

Option to expand or contract

This option refers to altering operating scale depending on market conditions, including shutting down temporarily (mothballing) and restarting when conditions become favourable again.

Option to abandon or terminate unprofitable projects

Being able to terminate the project while in the phase of an investment is an option that has value if the project turns out to have negative value during the phase of investment. The abandonment

Option to switch, change inputs or outputs

Companies that can switch from one input to another during course of investment when one input becomes more valuable than the other possess an option to switch use e.g. a refinery that can use both oil and electricity as inputs. If one of the energy inputs becomes uneconomical the company can alter the input.

Option to stage

A company can break up its investment into incremental phases (sequential investment) where the payoff occurs only after the project is completed e.g. investing in R&D and commercialization processes for bringing a new drug to market.

Option to grow

This involves investing in an initial market, product line or technology to develop a platform for future growth opportunities. Even if the initial investment might have negative value, the value of the subsequent (growth) investment can bring value to the investment project and make it economically viable.

3.3 Applications of Real options theory

Two main application streams that use real option theory have emerged. The first is intrinsic to financial literature and can be referred to as financial engineering. In this context contracts and investments are valued using real option theory. The aim of this research stream is to quantify the value of options. This stream has had a great impact on investment practice and real option valuation is emerging as a new standard for valuing, selecting and managing strategic investments and existing companies (Standard and Poors, 2004). Real options are preferred to e.g. traditional discounted cash flow (DCF) valuations of new firms because such firms face high degrees of uncertainty, have no track record and have negative cash flows. This is because DCF's tend to undervalue firms by not considering their future options (e.g. the possibility that patents could allow the firm to enter new markets) (Damodaran, 2001). Furthermore, real option theory has been used to value companies that have high market to book values by incorporating growth options of companies in their valuation.

The second application uses real option theory from a qualitative perspective to explain decisions of firms and individuals under uncertainty. The theoretical framework of real options has created excitement in the management literature in recent years (Kogut and Kulatilaka, 2001; McGrath, 1997) and several research works have adopted real option reasoning to explain and analyse phenomena by gaining new and unique insights (Miller & Shapira, 2004; O'Brien et al. 2003; Miller & Arikan, 2004). According to McGrath (1999), real option reasoning can provide the conceptual foundation for new perspectives on the dynamics of performance, survival and choice in entrepreneurship as well as a valuable addition to established theories of learning, decision-making, and organization.

The rather wide applicability of real option theory, due to its generality and its scope for a wide range of applications, has caused a debate among academics about its boundaries and what units of analysis can be modelled as real options (Adner and Levinthal, 2004). Table 3-1 gives examples of the applicability of real options in recent literature.

Table 3-1: Applicability of real options in recent literature

Real options as	Reference
Buyouts	Folta and Miller, 2001
Joint ventures	Kogut, 1991
Equity stakes in partner	Folta and Miller, 2002
Incremental R&D investments	McGrath and Nerkar, 2004
Entrepreneurial initiatives	McGrath, 1999
Firm capabilities	Kogut and Kulatilaka, 2001
Incremental capital investments	Hurry et al., 1992

3.4 Patents as real options

The paradox of innovation is that it does not provide the innovator with an incentive to commercialize it. Innovators have to make large investments in developing new technologies and knowledge which can then be almost costlessly imitated when the innovator demonstrates the new idea to the world (Arrow, 1962). To create incentives to innovate, intellectual property rights (IPR's) are required to give the innovator the right to control the use of the innovation and hence the revenues from it. One of the most common IPR's are patents which are government-sponsored monopolies, designed to reward the inventor by providing him with incentive to risk time, effort, and money in developing new technologies.[3] (see e.g. Lerner, 1994[4]).

A patent provides the patent holder, or patentee, with the right to exclude others from making, using, selling, offering for sale, or importing an invention for a limited period of time without permission from the holder. The patentee then has the option either to commercialize the patent by exploiting its features himself or to sell it to others in form of a license, usually for a fee known as the royalty. The license provides the owner with the legal right to use the innovation for a fixed period of time. In the UK a patent is legally protected for 20 years from the date the patent is granted but is typically far shorter as we will show later. The monopoly regulation encourages innovation while the eventual extinction of the rights permits diffusion. Through a governmental regulation of

[3] Another important form is copyrights.

the market of innovations, the paradox of innovation mentioned earlier is resolved through the possibility to protect the innovation through a patent.

Universities that have developed a patent have two possibilities open for commercial gain: either set up a business itself to exploit the patent (i.e. create a spinout company) or license the innovation to someone else. Exercise of the option then consists in the decision to make an investment in a start-up company; non-exercise consists in waiting and deferring the exercise to a later point in time and selling the option refers to licensing it out. We will take a similar approach to Kogut (1991) who has exemplified joint ventures as real options and observed the exercise of the option as the acquisition of the venture (spinout).

In financial option theory, two types of options can be distinguished, namely put and call options. A put option provides its owner with the right, but not the obligation, to sell the underlying asset, where as the call option provides the owner with the right to buy it within a fixed period of time called the exercise period. Both types of options can be differentiated further into European and American options, where European options can only be exercised at expiry date while American options can be exercised at any point in time. In terms of real option theory, the patent presents an American call option as it provides the company or institution that owns it with the right to make the investment and commercialize the patent at any point in time up to the end of the patent's life.

The exercise period for this real option is thus the life of the patent. Licensing is equivalent to selling the right to set up a firm to produce using the patent, and corresponds in finance to selling the American call option.

For an existing company that possesses a patent, the exercise of the option would mean an investment in a commercialization project within the company, whereas for a university exercising the option is only possible via the setting up of a hierarchical form of governance like a new company (i.e. university spinout company). Selling the patent to another company (licensing) can be considered equal to selling the option and distributing the right of commercialisation to another entity. Therefore, universities are faced with three possibilities, when facing the decision to commercialize a patent. They can sell the patent and gain royalties, commercialize the patent in form of a spinout or hold the patent and wait.

Much of the financial option theory is based on the work of Black and Scholes (1973), who have developed a valuation method that can value European options (options that cannot be exercised before its expiration date). The value of options prior to expiration is according to Black and Scholes (1973) given by

$$C = f\ (S, X, \sigma, D, T, r)$$

Although patents represent American options (options that can be exercised before its expiration date) the framework of Black and Scholes can also be used to qualitatively assess the key influencing factors on real option value (Damodaran, 2001). Therefore, replicating the Black and Scholes equation and transferring it into the university setting can provide a rudimentary starting point to value the option. Table 3-2: Comparison of financial and real options

shows the factors that influence the spinout option.

Table 3-2: Comparison of financial and real options

	Factor	Financial Options	Real Options (RO)	Comment
C	Value of right to buy the underlying asset at a price X within time period T	American call option value	Value of selling the patent or equivalently of selling the right to commercialise the patent to an outsider to the university	Real option value is not traded in the market and has to be estimated.
S	Value of underlying asset	Current Share price	Present values of the cash flows that would be obtained from the spinout	Underlying value is not traded in the market and has to be estimated
X	Strike price	share price on which financial option is exercised	cost of commercializing the patent and developing necessary technology into a spinout usually representing investment cost	Strike price for RO is time variant and follows a random process due to input and technology uncertainty (Dixit and Pindyck, 1994)
σ	Volatility of underlying asset	Volatility of share price	Volatility of underlying investment	RO market uncertainty cannot be observed in the market like e.g. implied volatility. Further it has to be estimated from a 'twin security' that is traded in the market
υ	Volatility of exercise price	Volatility of exercise price	Volatility of technology	
D	Dividends	Dividends to shareholders	Expected dividend payments of investing in spinout	
T	Time to expiration	Time to expiration of option	Effective time to expiration of patent or time until investment in spinout can be deferred	RO expiry can change due to e.g. exogenous shocks like entry of competition
r	Riskless interest rate	Opportunity cost of investment	Opportunity cost of commercializing the patent	

Value of underlying asset (S)

Patents protect technologies and processes and would be of no value if the firm has no intention to commercialise them. Universities can use patents to commercialize new products, develop processes in-house that are protected, license the intellectual property (IP) to other companies but also have the option to spinout new companies. The value of the underlying asset (S) refers to the cumulative revenues and cash flows that the patent can generate if it is commercialized in form of a spinout and equals the net present value of the spinout (including expected future cash flows as well as future growth opportunities).

Cost of investment(X)

The exercise price or strike price X is in financial terms the fixed price the underlying stock can be bought with the call option or sold with the put option. In real option terms it is the initial cost of the investment project. This cost of investment can be distinguished into the cost of commercialization and cost of technology development (McGrath, 1997). The cost of commercialization refers to the cost to create the necessary infrastructure, market the technology as well as acquire the right people. Technology development costs can be considered as investments to create a commercial technology, namely R&D efforts, design, prototyping, testing, idea and model development expenses since patents are usually in a premature commercial phase. Ex post the development cost can be calculated and estimated whereas ex ante the development cost underlies different uncertainties, which will be considered later.

Option Value (C)

Option value C represents the value of the patent that can lead to a spinout and therefore the value of the spinout option. Viewed from the present it is the expected maximum of the difference at exercise between the underlying investment value (S_t) and the commercialization cost (X) and the return to leaving the option to expire worthless (0). The profit from exercise at expiration is simply the difference between S and X provided this is positive (option is 'in the money'). This wealth increment to the university is the return to of the present value (PV) of cash flows from the business S minus the cost of setting up the business X.

Market and Technology Uncertainty (σ, υ)

Real options are susceptible to a wider range of uncertainties than e.g. financial options, which value is only affected by the uncertainty regarding the underlying asset (stock price volatility). Dixit and Pindyck (1994) have shown that real options on investments are disposed to two main uncertainties namely, price and cost uncertainty. Price uncertainty refers to the uncertainty of the future value of an investment. Cost uncertainty on the other hand encompasses the uncertainty regarding the cost of the investment (opposed to its payoff) and has different implications for the likelihood of investment and its timing. Price and cost uncertainty are also apparent in university spinouts. Price uncertainty can be understood as the uncertainty regarding the future value of the spinout. Cost uncertainty on the other hand can be inferred to as the uncertainty regarding the cost of investment. Dixit and Pindyck (1994) have further divided cost uncertainty into input cost uncertainty and technological uncertainty. Input cost uncertainty cannot be influenced by the investor itself and arises e.g. when a spinout needs material and resources to build a factory and the prices of these materials and resources vary stochastically over time. Input cost uncertainty is therefore external as the spinout cannot take any action to influence it. On the other hand the technological uncertainty considers how much time, effort and resources the entrepreneurs will need to physically develop the technology into a commercial stage and relates to the costs and probabilities of technological success (McGrath, 1997).. Technological uncertainty can therefore be influenced directly by the entrepreneurs' competence, experience and ability. However, it too, will have an exogenous component.

Unlike other empirical studies that only evaluate effects of price uncertainties like e.g. demand or market uncertainty; we will include also cost uncertainty in our study. To accommodate uncertainty regarding underlying value (price uncertainty) we will look at the market uncertainty (σ_m) of the particular industry.

Expected Dividend Payments (D)

Expected dividend payments indicate the expectations regarding the earnings an investment can generate in the future. The higher the expected dividend payments for investing now, the higher the opportunity cost of delaying commercialization. Expected dividend payments are not only a financial dimension but can also represent expected first mover advantages, gain of experience etc. In the next chapter the dividends will be elaborated in detail.

Duration of Option (T)

In optimal case the duration T is equal to the time until expiration of the patent, which is normally 20 years from the patent publishing date. But patents do not exist in a vacuum and competition is agile to imitate or substitute the patent if the invention is of high value. Therefore T represents the effective patent life, which is influenced by competition and is normally shorter than 20 years. Mansfield et al. (1981) reported that 60 per cent of patented innovations were imitated within 4 years. This shows that patenting has not the aim to prevent but rather to delay imitation and substitution. It is the competition that realizes the value of the commercial opportunity and tries to imitate or substitute the patent and therefore reduce its expiration date. Therefore, time to expiration T is often determined by the time competitors takes to enter the market and excess returns of the patent diminish.

Risk free rate of return (r)

R is the risk free rate of return. Although the risk-free rate of return may also have a bearing on the optimal timing for real options, its influence is weak and ambiguous for real options (Dixit and Pindyck, 1994). Similar to Folta and Miller (2002) we may therefore neglect it in our study

4 Patenting Processes and Patent Research

4.1 Patent Analysis and Patenting Process

Traditionally patent analysis was used for carrying out comparative research of simple patent counts for purposes of identifying key technologies and their origination. More recent approaches involve patent citation analysis that implies many data-harvesting activities, ranging from simple documentary search of related papers and patents to more complex studies on trends in technology innovation and development. In the last few years, patent citation analysis is being increasingly used in technology and innovation research due to improved quality of data as well as the availability of public databases that provide easy access to researchers.

The patenting process can be summarized in two main steps (http://www.wipo.int/pct/en/texts/articles/atoc.htm), namely producing the search report, and checking for patentability of the invention.

4.1.1 Search Report

Upon submitting a new patent request, the patent office checks the originality of the invention by checking relevant prior art where prior art refers to everything which has been made available to the public anywhere in the world by means of written disclosure. Patent search is the process of checking prior art to determine if the invention involves an inventive step which requires a detailed search of all documents publicly available before the international filling date, including other patents, books, journals which are categorized as non patent literature (NPL). Performed by the Patent Cooperation Treaty (PCT) international patent searching authority, this process analyses descriptions and drawings contained in the new application and checks them against as many prior art documents as possible, which is referred to as consulting the "minimum references". The result of this process is a fully documented patent search report, which represents the outcome of the authority's work of consulting large numbers of prior art documents that are in any way technically related to the patent application.

The information contained in the international patent search report must be detailed and accurate and must show the classification of the technical subject of the patent as well as cite all relevant prior art. Furthermore, for all cited documents, the relevant passages must be indicated by means of page number, line or paragraph number in order to ensure clear identification. When documents are linked only to specific claims it must be pointed out to which. Furthermore the sources of the searched documents have to be documented including the names of the databases and keywords used during the search process.

From the legal point of view, the patent search report is used to define the scope of legal protection. By scanning all the citations, the search report allows to set legal boundaries of the claims by establishing what knowledge was already available at the filing date. Based on the patent search report, an "assessment of patentability" is created. Search reports assign grades to each citation, which divide the citations into categories of relevance. US search reports fall out of the general rule by not assigning relevance grades to citations and have other diverging attributes that will be discussed later.

4.1.2 Patentability

Three different criteria need to be assessed to ensure patentability of a patent application (Michel and Bettels, 2001):

- Novelty
- Inventive activity
- Industrial applicability

If one of these three criteria is not fulfilled, the patent application will not be successful. Missing documents of technical importance in the patent search process decrease therefore chances of a successful patent grant. The European Patent Office states that a patent search report of good quality will contain most information of technical importance in as few documents as possible. Usually the majority of important information can be obtained from 1-2 documents (Michel and Bettels, 2001).

While all criteria have to be assessed, the difficulty of evaluation can differ across categories. Checking for novelty can be an elaborate and complex task but it is relatively straightforward as selected technical documents have to be compared against the patent application. There can be much more debate over the evaluation of the criteria of inventiveness. An answer has to be given as to whether finding a solution to a given problem was obvious in view of the technically closest document, called the closest prior art. What is obvious or not can be very tricky to evaluate and traditionally, different national or regional offices have taken different approaches to this problem. The process itself is complex and defining what is obvious and what not can become a very delicate issue. Various patenting offices have various policies related to inventive activity, and each of them has different boundaries for delimiting this criterion. Due to varying requirements for the inventive steps across different patent offices, this can result in a situation where the same patent is granted in one country and denied in another. Industrial applicability can be usually assessed immediately without requiring any particular further assessment.

4.2 Patent citation statistics

4.2.1 National applications

The US patent office (USPTO), the European patent office (EPO), German patent office (DPMA) and the Japanese patent office (JPO) handle a total share of 90% of all worldwide patent applications. A comparison of the European and US results reveals major differences for patent and non-patent citations. The citation numbers for the US patent office are in the order of 3 to 3.5 times higher than its European counterpart. European, UK and German offices produce similar values of patent citations as the EPO, but less non-patent citations compared to the EPO. UK figures are a ca. 25% and German office figures ca. 50% of the non patent citations compared to the European patent office (Michel and Bettels, 2001).

The differences between US and European patent offices can be explained due to differences in the legal environments. Every patent applicant in the US is obliged by law to provide a thorough list of prior art citations upon filing for a patent otherwise the patent request will be rejected. This results in a very large number of reference citations which can have both positive and negative effects on the usefulness of patent citations. One is that selectivity of relevant patent citations becomes more difficult but on the other hand coverage of the used technology increases. The European patent offices on the other hand do not bind the applicants legally to provide a list of prior art. Regardless of such a list being supplied or not, both the EPO and the JPO thoroughly scan citations relevant to the patentability of the invention as a part of the normal patentability search process.

4.2.2 International applications

International applications according to the PCT permit simultaneous filing of a patent application in more than 100 countries. The legal framework governing the filing of international patents is subject to the PCT constituted by ten International Search Authorities (ISA) that produce the required international search report. All ISA's have to respect the framework of the patentability search report specified by the World Intellectual Property Organisation (WPO). The three major offices (EPO, JPO and USPTO) are responsible for processing the largest number of international patent applications. Governed by a common legal environment, the discrepancy among the number of citations of the three offices disappears. The resulting figure of international patent applications is approximately 4 references per application, which is close to what the same offices, with the exception of the USPTO, are producing at a national scale making the references of international patent application comparable to the EPO, JPO and DPMA. When looking at the non patent citation (NPL) statistics for international applications the EPO produces one and a half times more NPL than the USPTO.

If the same application is filed in more than one country, it will be called a patent family. The comparison will be made between average citations per patent family and average citations per total patents (i.e. both those having and those not having families). The USPTO is again about 3 times higher that the other offices, with figures of 14.26 average citations per patents with families, and an average of 12.96 citations for the total patents. The European office produces values approximately similar for patents with families – 4.18 citations, and total patents – 4.37 citations. Interestingly, both USPTO and EPO produce twice as much NPL per patent families, than per total patents: EPO shows figures of 1.47 and 0.85, respectively, while USPTO is again 3-4 times higher with 6.29 and 2.98, respectively (Michel and Bettels, 2001).

Table 4-1 Frequency of Patent Application by patent office in the Max Planck database

WPO	EPO	DE	USPTO	not applied
61.08%	15.95%	20.76%	2.21%	79.04%

Table 4-1 gives an overview of the frequency of Max Planck's patenting frequency grouped by patent office. The first decision of the technology transfer office when receiving an invention disclosure from one of its institutes is to decide on the geographical scope of the patent application. As can be seen in Table 4-1 out of all patent applications the majority of technologies are applied to the WPO (61%) where subsequently individual patents in individual countries can be applied for. A relative large number of inventions are anticipated only for the local market (Germany, 20.7%). Max Planck has a minor fraction of patents (2.2%) that are exclusively applied for at the USPTO. These patents were ignored in the analyses in subsequent chapters in order not to skew the analysis due to the differences in the patenting approach of the USPTO. The fraction of invention disclosures that are not commercialized at all or are not going via the patent route (e.g. secrecy agreements) is 79%. It should be noted that in the analyses the patent applications rather patent grants are used as the basis for observation of the invention.

4.2.3 Patent Citations and the Value of Patents

A limitation in assessing the trend of innovations based on patents is that not all inventions are subject of a patent. Multiple reasons can be accounted for this e.g. personal choice of the inventor who may not want to expose a secret, non-compliance with the patentability conditions or the decision of the technology transfer office to commercialize the invention via secrecy agreements. Due to non systematic existence of data about inventions that are not patented it is almost impossible to establish the number of inventions that are not subject of a patent (Crepon, Duguet and Mairesse, 1998). Still economic research focuses on patent data as it is the best obtainable measure to study the effects of invention dynamics and innovation patterns. The first studies using patent data were conducted by Scherer and Schmookler in the 1960s and major advances in innovation research using patent data were performed by Griliches in the 1980s. In the light of things shown earlier, the results of these studies, though are somewhat impaired by the fact that patents are the only criteria used for evaluating innovation. In addition, different patents have different technological and economic value, and therefore any statistic that uses raw patent counts will not be able to highlight the varying amount of innovation each patent brings (Griliches et al., 1987). Further work on this subject has managed to bring more quality to the assessment of the economic value, by using patent renewal data or patent citations (Trajtenberg, 1990) instead of raw patent count, thus taking into account the varying levels of innovation present in patents.

Looking closer at patent citations, several pieces of information can be extracted, of which some can be extremely useful for the study of economic value. Thus, citations reveal the existing connections, both in terms of time and geographical area, among different inventions and their respective inventors. Any citation of an already existing patent indicates that money was invested in buying the rights to use the existing technology, and since any investment is made with profit in mind, this is an indication that the cited patent has a certain economic value. This creates a method to scale the otherwise hard to measure value of patents. Moreover, a citation appearing in more and more documents as time passes by is a clear indicator of the increased value of the cited patent, whereas a few citations of a fresh patent may just be exceptional and of no relevance to its corresponding economic value. Studies by Jaffe et al. (2000) confirm that citations can be used as an indicator of innovation levels transmitted among patents.

In the 1990s, Trajtenberg researched the link between social surplus and innovation in medical imagery (Trajtenberg, 1990). Patents related to CT scanners were, on one hand, roughly counted, and on the other hand, evaluated based on citations. In both cases, a link to the social surplus brought by each innovation was established. In the case of raw counts, no such link could be created, but citation-evaluated patents showed a high level of linkage to the amount of social surplus, therefore demonstrating that citations are a good indicator of the economic value. Adding more criteria to the citation-based evaluation may create an even better tool for value analysis. In a study, criteria like the number of countries and the number of claims of a patent were added to the existing citation evaluation, and the subsequent results allowed researchers even to guess which of the patents will or will not be renewed, which is also strongly connected to the value of patent (Lanjouw and Schankerman, 1998). In another study, patent owners around Germany, who had property on patents originating in the US, were hypothetically placed in the position of selling the patent as it became three years old. A strong correlation between the selling price and the citations was found, with values going as high as a million dollars per citation for the patents having the most citations (Harhoff et al., 1999). Such results were also reported by other studies focusing on the real revenue obtained by employed patent holders under the jurisdiction of a legal frame concerning employee compensation.

An additional line of research also focuses on major companies, creating a link between their stock exchange values and their policies concerning research and development, knowledge investment and patents. Patent counts were tried to be introduced to such research for extra information, but proved to be less enlightening in this respect, than is the R&D itself. The results of introducing patent citations to such research are more encouraging, even if R&D is also taken into account. Citations provide good results when used in Tobin's q equation. A study conducted by Shane (2001b) showed that patent citation generally correlated well with R&D, unlike patent counts.

The amount of correlation between patent counts weighted by citations and economic value is however highly dependent on the actual industry field the study is conducted in and therefore it is important to control for the industry level when conducting research based on patent data.

4.3 Patenting and technology commercialization at the Max Planck Society

The Max Planck Society (MPS) is Germany's largest non-profit basic research organization which maintains its own 78 institutes (as of 1.1.2006) for the purpose of performing cutting-edge basic research. Currently the institutes employ over 12,000 people including 4,300 scientists. In addition, there are also around 10,900 doctoral candidates, post-doctoral fellows and visiting scientists from abroad which form the base of Max Planck's human capital.

The Max Planck Society is largely financed by federal and state grants which amounted in 2006 to €1.38 billion. As a non-profit research organization the scientists are obliged to make the results of their work accessible to the general public. Industry cooperation, granting of patents and licenses, and the founding of spin-off companies are the key elements of commercializing research at the MPS. These tasks are handled by the technology transfer office (Max Planck Innovation) founded by MPS.

Max Planck Innovation was founded in 1970 under the name Garching Instrumente GmbH and operated under the name of Garching Innovation from 1993 to 2006. It negotiates and closes agreements on behalf of the Max Planck Society. Income from license agreements is almost completely transferred to the inventors, the Max Planck Institutes and the Max Planck Society. Company shares acquired during licensing negotiations are owned by the Max Planck Society. The shareholder agreements are negotiated by Max Planck Innovation and signed by the Max Planck Society.

The main tasks of Max Planck Innovation include:

- Advising and supervising patenting process of MPS inventions
- Licensing inventions
- Spin-off creating and support including coaching and advising founders
- Advisory role in supporting scientists of the MPS in evaluating inventions
- Marketing innovations through a wide ranging network of industry contacts

Currently, Max Planck Innovation oversees more than 1,113 inventions and is a shareholder in 15 companies. On average each year an additional 150 projects are taken on. Since 1979 over 3,000 inventions have been managed and advised and more than 1,700 license agreements closed and more than 80 spin-offs coached (since 1990). The total proceeds for inventors, the Max Planck Institutes and the Max Planck Society currently amounts to about €260m. As a result, Max Planck Innovation is worldwide one of the most successful technology transfer organizations.

4.3.1 Patenting and Licensing

According to Max Planck Society employment contracts and also to the Employees' Inventions Act, all occupational findings or ideas that may have inventive character must be reported to the institute's management. Especially premature publication of research results represents the greatest danger to the patentability of inventions according to MPS. Publications in this sense include not only journal articles, but also speeches, lectures, presentations at conferences and seminars, as well as disclosure of data and results on the Internet. Therefore scientists are required to hand in a special form named the ‘invention disclosure form’ to Max Planck Innovation as soon as possible in order to initiate the patenting process.

After receiving the invention disclosure form the TTO examines whether the invention is likely to lead to a successful patent application and evaluates its commercial potential. If the evaluation is positive – and after clearance with the scientist and the Max Planck Institute, who meet the costs of the application – the TTO instructs an independent patent attorney experienced in the relevant field to draw up the patent application.

During this process the inventor is required, to the best of his ability, to support the Max Planck Society in its efforts to apply for and commercialize his invention. As a rule, the accompanying know-how of the scientist is necessary to enable a future licensee to realize the economic potential of a product based on the invention.

Inventions made by MPG staff members usually emerge within the scope of their research activities or are based on the institute's experience or work. These inventions are thus called "employee inventions". In accordance with the German Employees' Inventions Act, the employer, i.e. the Max Planck Society, is entitled to such inventions.

The compensation of the Max Planck scientist is handled as follows. According to the current MPS regulations covering Employees' inventions the scientists generally are entitled to receive up to 30% of the gross license income that Max Planck Innovation receives from the commercialization of their IP or know-how. This compensation exceeds the minimum rates of indemnification for employee inventions provided for by guidelines currently in force in private industry and in the public sector, and is intended to motivate the scientists to participate actively in technology transfer.

4.3.2 Spinout Companies

The TTO takes a comprehensive approach towards spinoff creations and supervises the entire founding process including set-up phase, evaluation and discussion of the business idea, support in business and finance planning, patent supervision and connection to network partners and by providing management coaching

Each scientist who plans to commercialize an invention can become a shareholder in a spin-off. The involved scientists may as well choose to become an employee of the new company, but in that case they must resign at the Max Planck Institute due to possible conflicts of interest. Further if they want continue their scientific carrier as an employee of the Max Planck Institute they can take an advisory role subject to prior authorization by the institute itself.

However the acceptance of an executive or managerial position will not be allowed in concurrence with a scientific role at MPS.

The policy towards investment in the spinout company is handled in following way. Neither the Max Planck Society nor Max Planck Innovation is in the position to invest capital in spinouts. However, the Max Planck Society may act as a technology investor and waive an upfront payment when granting a license to a spinout, in return for shares in the company. This waiver is analogous to a financial investment and the Max Planck Society is therefore requesting typical rights of a co-investor.

4.3.3 Max Planck Innovation Database

The Max Planck database has been acquired from the Garching Innovation Gmbh in 2003 and contains comprehensive information on all inventions from 1990. Detailed description of the variables used in this research can be found in the Appendix. Since the research in this thesis will mostly focus on the creation and termination of commercialization opportunities, Figure 9-6 and Figure 9-7 in the Appendix show a summary of different activities over the time horizon from 1990 to 2003.

Since the MPS dataset is one of very few datasets that follows the lifecycle of an invention from inception to termination, Table 4-2 shows the comparison between the two other existing datasets in this area which contain information on commercialization activities from the Massachusetts Institute of Technology and University of California.

Table 4-2 Comparison of datasets existing on lifecycle of innovatons and patents from public research organiztions and universities

	Shane [a]	**Ziedonis** [c]	**Thesis**
Institution	Massachusetts Institute of Technology	University of California	Max Planck Society
Time Period	1980 - 1996	1979-1998	1990 - 2003
Industries	Chemical Drug Electrical Mechanical	n/A	Chemical Drug Electrical Mechanical
Number of USOs	134	36	82
Number of Patents	1397	669	1640
Number of Licenses	1032 [b]	309	950 (individual) 1123 (multi)
License Terminations	338	n/A	484

a Shane, 2001b

b Katila and Shane, 2005

c Ziedonis, 2007

5 The effects of market and technological uncertainty on university spinout formation and spinout failure

5.1 Introduction

High technology industries are characterized by a volatile and a rapidly changing environment where new technologies are constantly evolving under dynamic market conditions. Technologies are research intensive and exposed to uncertainty regarding their successful development and functionality. On the other hand these technologies have to be absorbed by volatile markets in order to be commercialized. The question under which conditions high technologies are exploited especially through firm formation and under which conditions companies fail and shutdown operations falls under the category of economic organization and has traditionally been discussed within the theory of the firm.

Empirical studies correlated high technology firm formation with research and development intensity (Scherer 1980), cross-industry variation in technology life cycles (Utterback and Abernathy 1975, Gort and Klepper 1982), strong appropriability conditions (i.e. the economic benefit of an innovation can be adequately be captured and protected by the innovator) (Levin et al. 1987, Nelson and Winter 1982), capital availability, firm size, and industry concentration, though most of them with contradictory findings (Shane, 2001b). Recent studies on high-tech formation focused mainly on academic spinouts allowing researchers to understand a wide range of determinants of firm formation and expand different theoretical concepts (Djokovic and Souitaris, 2008). Researchers found that the main determinants influencing their inception are institutional factors of the parent organization, geographical location, market and industry conditions where the technology is commercialized as well as the nature of the technology.

Research that focused on the relation between the parent institution and its incumbents (institutional factors) showed that distribution of larger royalties to inventors (Di Gregorio and Shane, 2003), willingness of the parent organization to take higher equity stakes in return for paying patenting and other up front costs (Di Gregorio and Shane, 2003), benefiting university policies towards spinout creation (Tornaztky et al., 1997), allowing leaves of absence to academic inventors, ease of use of university resources (Tornaztky et al., 1997), availability of pre-seed stage capital (UNICO, 2001) and characteristics of technology transfer offices (UNICO, 2001) increase spinout activity.

Another research stream focused on environmental influences and how geographical location influences the rate of spinout formation. Main determinants that were researched in the spinout setting are accessibility to capital and proximity to venture capitalists (Di Gregorio and Shane, 2003), locus of property rights e.g. locating ownership rights at the individual (researcher) vs. a higher organizational (university) level (Goldfarb and Henrekson, 2003), rigidity of academic labour market and industrial composition of area (Shane, 2004b).

A small number of studies discussed how market and industry specific conditions influence their formation. Among them mainly Shane (2004b) proposed that the tendency for an invention to be exploited through firm creation varies with the attributes of the technology regime (the age of the technical field, the tendency of the market toward segmentation, the effectiveness of patents, and the importance of complementary assets). He tested this set of hypotheses empirically in a university spin-out setting. Other studies showed that with increasing number of firms in the industry, spinouts are more likely to occur (Shane and Katila, 2003).

Research on the nature of technology that influences the likelihood of spinout generation found that only a small proportion of university inventions are suitable for creating spinouts. It shows that radical technologies (Vohora et al., 2002), tacit knowledge, early stage invention and general purpose technologies that have strong intellectual property rights (IP) protection (Shane, 2001a) are more suitable than other technologies to provide the basis for spinouts.

On the other hand, firm failure and survival of university start-ups has been studied from different theoretical angles which included analysing the social ties of founders (Shane and Stuart, 2002) as well as their regional networks (Saxenian, 1990). Rothaermel and Thursby (2005) found that spinouts with strong ties to their parent organizations were less likely to fail but also less likely to successfully graduate within a timely manner. Moreover, in a comparison between new technology-based ventures and university spinouts Ensley and Hmieleski (2005) showed that spinouts were not necessarily better performers.

On a more general scale researchers have studied the failure of firms in relation to their technological competency (Henderson, 1993; Christensen and Bower, 1996). They found that established companies are more likely to be replaced by new firms when their technology competency was not valuable to their customer base. More recently Shane and Nerkar (2003) extended this line of research and showed that firms with radical technology and a broad patent protection in fragmented industries increase their likelihood of survival.

Although existing research findings present a reasonably complete framework in explaining why some technologies are more suitable than others for firm formation and firm failure, we have identified four major novelties of our study to current research on new firm formation as well as firm failure:

Firstly, the finding that university spinouts based on early stage inventions are more likely to occur needs more evidence and scientific verification (Shane, 2004b). Research omitted the influence of uncertainty on new firm formation, to which high technology ventures are particularly exposed. Existing research investigated the influence of external uncertainty on existing firms entering new markets through equity partnerships (Folta and Miller, 2002) and joint ventures (Kogut, 1991) by embedding a real option perspective. Folta and O'Brien (2004) used a sample of 17,987 firms from different industries and showed for existing firms entering new markets, that the effect of uncertainty is non-monotonic and demonstrated that entry is moderated by the presence of investment irreversibility, total value of growth opportunities and first mover advantage. We will fill the gap why new companies rather than existing ones are entering markets and will explore under what conditions of uncertainty, predominantly to be found in early stage technologies and research intensive industries, firm formation is the dominant mechanism of technology commercialization. In particular, we will examine the effects of exogenous (market) as well as endogenous (technology) uncertainty on spin-out activity and analyze how they are affected by passage of time. Therefore, our study will be the first to study both, the influence of exogenous (market uncertainty) and endogenous uncertainty (technological uncertainty) on the entry of new high technology firms.

Secondly, research on firm failure has not examined how the market and technological regime the newly established firm is found in affects its survival. Therefore this research tries to close this gap by offering an explanation to how the market and technological uncertainty affect new venture failure.

Thirdly, we will use a new theoretical approach to tackle these research questions by grounding our findings on the foundations of real option theory (ROT) in order to consolidate uncertainty and timing of entry and failure into one theoretical framework. Although other theories like e.g. transaction cost economics provide a theoretical framework how uncertainty affects hierarchical form of governance of market transactions, they deal with different types of uncertainty that affect economic organization (e.g. behavioural uncertainty). Further real option theory can explain the dynamics of entry and exit which other theories do not entail. Therefore the real options framework can contribute to our understanding of entry and exit timing of investments (Miller and Folta, 2002) as well as experimentation and the proactive exploration of uncertainty (McGrath, 1999)

Lastly, most of the studies on spinout formation are using qualitative approaches and are based on interviews with technology transfer officers. Our study relies on quantitative data to explore firm formation as well as firm failure. Although a small number of studies have utilized quantitative data on spinout creation all of them relied on a single research institution in the US. Our study is the first to explore a quantitative dataset outside the US.

In order to consolidate the two concepts of uncertainty and timing, we will extend real option theory to technology commercialization decisions by taking the perspective that uncertainty influences the value of the technology option as well as the timing of exercising it.

5.2 Theory Development and Hypothesis

Real option theory is an investment theory that identifies factors that affect the threshold at which investment is to occur rather than the level of investment itself (Dixit and Pindyck, 1994) and discusses optimal decision rules on investments under uncertainty. Real option theory is derived from the Nobel Prize winning option models of Black and Scholes (1973) and in contrast to their financial counterparts, real options represent usually investments in non-financial assets with an uncertain payoff that convey the right, but not the obligation, to exercise the investment, should the total payoff look attractive (Damodaran, 2001). Therefore real options protect the holder against downside risk, since the expiration of the real option without exercising can only lead to the loss of the right rather than the whole investment itself.

The basic unit of analysis is the real option and real option theory is based on several assumptions with the most significant being that investments are not fully reversible due to the nature of investments which are industry or firm specific and therefore cannot be fully recovered (Dixit and Pindyck, 1994). ‘This assumption is critical because if investors cannot fully recover sunk costs, the initial investment decision depends on expectations about uncertain future cash flows' (Miller and Folta, 2002).

A newly developed technology can be viewed as a real option for the hypothetical investor who can: (i) choose to maintain flexibility by withholding the investment, (ii) increase its commitment by exercising the option in form of a spinout company or (iii) sell the option in form of a license. Once the spinout is formed the equity holders of the spinout can sell or terminate the operation if it seems unprofitable. In option logic and terminology the option to sell or terminate the operation can be considered as holding a put option and selling or exercising it. In this paper we will exclusively focus on the exercise of the call option and creating a spinout as well as exercising the put option and closing down operations of a spinout.

This section provides a framework that will be used to identify and clarify how different forms of uncertainty and other variables influence the entry and exit decision. We will extend the function by Miller and Folta (2002) that captures the incremental value of holding the call option to actually exercising it (creating the spinout) and therefore create a systematic framework for analyzing the decision to form a spinout. Further we will investigate under what conditions of uncertainty exercising the put option (abandoning the spinout) is the optimal decision.

5.2.1 Uncertainty and the entry decision

Neoclassical investment theory analyses the simple net present value of the investment and as long as it is positive the investment should be made. The decision making rule for investment entry is:

$$\text{Enter If: NPV} >= 0$$

This traditional approach neglects additional optional value of the investment project and neglects the influence of uncertainty of on the investment decision that is pertinent in the real option approach to capital budgeting decisions.

Usually investors fear uncertainty when having to make an investment as it diminishes the predictability of the profit (Dixit and Pindyck, 1994). Real option theory perspective inverts the usual thinking about uncertainty found in the organizational literature since uncertainty can create opportunities when it is properly understood (Amram and Kulatilaka, 1999).

As noted earlier market uncertainty is a form of exogenous uncertainty and is unaffected by actions and can only be resolved over time. Premature investments under high market uncertainty impose certain risks as the hypothetical investor disregards the value of waiting and receiving new information that might influence the attractiveness of the investment. Recent research on real options suggests that increasing exogenous uncertainty 'may not categorically dissuade entry investment through a monotonic decrease in the option premium' (Folta and Miller, 2002; Amram and Kulatilaka, 1999; Kulatilaka and Perotti, 1998) leading to the fact that when there are competitive advantages of early entry, higher exogenous uncertainty can increase the likelihood of commitment and firm formation which we will discuss later in this chapter.

Under the option framework when dividends (opportunity costs of not exercising) are not existing it is always optimal to delay exercising the call option as long as possible (for proofs see Miller and Folta, 2002 or Dixit and Pindyck (1994) who showed that it is never optimal to exercise an American option prior expiration date when no dividends or opportunity costs are present). It is known from financial option theory that the value of the option increases with increasing uncertainty regarding the underlying asset. Similar to a financial option, options on new technologies become more valuable when market uncertainty is high, that is when the future value of the underlying asset (e.g. technology) fluctuates strongly. This finding is consistent with innovation literature which has recognized that technology value increases if the underlying demand's potential variance and uncertainty increases (McGrath, 1997).

Exercising the option entitles its owner to a series of cash flows by committing a largely irreversible investment (X) by creating a spinout. The incremental value from maintaining flexibility by withholding the investment to increasing commitment and exercising it, is given by $V = D - X - C$,[5] where D is the present value of forgone dividends for not exercising the option early, X the exercise price depicting the investment necessary to create the spinout and C the call option value. Call option value (C) represents the opportunity cost associated

[5] The full notation can be written as $V(t, \sigma, \tau) = D(t, \sigma, \tau) - X(t, \tau) - C(t, \sigma, \tau)$, where σ represents market (exogenous) uncertainty and τ technological (endogenous) uncertainty.

with exercising the option (Miller and Folta, 2002) whereas Dividends (D) are potential cash flows only realized if the option is exercised prior expiration date and therefore represent the opportunity cost of not exercising the option and delaying investment. The dividend term is given in detail by $D = D_C + D_T + \alpha * D_G - D_D + D_L - D_P$,[6] where D_C are the discounted cash flows directly related to the real call option over the remaining option duration period, D_T are the discounted cash flows after the option expiration date, D_G is the value of the compound growth options that are only available if parent real option is exercised, α is a multiplier that enhances the value of the growth option if moving early gives the firm an the ability to expand beyond initial expectations (Liebermann and Montgomery, 1988), D_D is the value of the option to defer investment which value disappears when option is exercised early, D_L captures the value of technology learning due to investment commitment and exercising the option, D_P refers to strategic pre-emptive investments of competitors that reduce the value of the dividend payments. It should be noted that the optimal exercise time is when the present value of V reaches a maximum ($\frac{\partial V}{\partial t} = 0$).

Dixit and Pindyck (1994) have shown that the most valuable options which are affected by market uncertainty are the growth and deferment option which will be the focus of this study when analysing the effects of markets uncertainty on the entry decision. Further, one should point out the fundamental difference between firms competing in mature industries versus firms competing in knowl-

[6] The full notation can be written as $D(t, \sigma, \tau) = D_C(t) + D_T(t) + \alpha * D_G(t, \sigma) + D_L(t, \tau) - D_P(t)$

edge intensive industries which our sample represents. Miller and Modigliani (1961) have characterized the market value of the firm as being composed of present value of cash flows plus the present value of growth opportunities. The total market value of firms in knowledge based and emerging industries is primarily based on options to grow in the future (Myers, 1977). These options to grow can be seen as compound options on the initial real option and can only be obtained and its value captured by exercising the initial option and committing to investment.

Folta and O'Brien (2004) analysed how growth and deferment options affect the investment decision and showed that existing firms will enter new markets earlier rather than later when the net present value of the investment project is higher, forgone cash-flows (if entry is delayed one period) are higher as well as the option to grow (compound option) is more valuable and the option to defer is less valuable. Our research focuses on the entry of new firms. Both D_G and D_D are monotonically increasing with uncertainty as all other options are. The options to grow especially for new entrants are very sensitive to the uncertainty conditions they are found in compared to the option to defer. Early mover advantages and direct entry can result in immediate benefits and larger market share especially for entrants that are entering a high technology environment where technological advantages are strongly related to the competitive advantage of the firm. Further looking at implications from option pricing theory it can be seen that growth options are more sensitive to uncertainty compared to options to defer because their maximum value is not bounded (Folta and O'Brien, 2004) whereas the option to defer can never be larger than the initial investment required.

The variable D_G in the dividend function considers the value of the previously mentioned compound options and therefore predominantly reflects competitive advantages gained from moving early in emerging industries (Lieberman and Montgomery, 1988). The timing of the investment decision is primarily dominated by growth and deferment options and as shown earlier the sensitivity of the growth option towards market uncertainty is larger than that of the option to defer with increasing market uncertainty. This results in a nonmonotonic behaviour of market uncertainty on the investment decision to found a new firm. Furthermore, since for low market uncertainty the sensitivity of a growth option is small compared to the option to defer, the option to defer becomes the dominant value driver in low uncertainty environments. On the other hand if uncertainty is very high the sensitivity of the growth option increases and the option to grow becomes the dominant driver of investment value. Considering our value function we can see that if this relationship holds, as previously stated that this is the case in knowledge intensive industries, all other things being equal, following hypotheses are valid:

Hypothesis 1: The impact of market uncertainty on entry is nonmonotonic

Hypothesis 2: Market uncertainty will negatively influence the likelihood of commercializing patents through spinouts when uncertainty is low, and positively influence it when uncertainty is high

High technology companies are mostly created from high technologies in emerging markets that are prone to technological uncertainty (Abernathy and Utterback, 1978; Schumpeter, 1934). Researchers have also recognized that early stage technologies with high technological uncertainties are more likely leading to spinout formation. However they were unable to make this idea precise by placing in a formal theoretical setting (Shane, 2004b).

Technological uncertainty represents the uncertainty about the success and feasibility of the developed technology and the uncertainty if the underlying technology will satisfy quality, performance and standards that were initially intended (Dixit and Pindyck, 1994). In the academic spinout context technological uncertainty can be considered as the uncertainty about the time, effort and other resources needed to successfully create the spinout and develop the underlying technology according to its specifications. The major difference between market uncertainty which is exogenous and technological uncertainty which is endogenous is that endogenous uncertainty can be resolved through active investment of time and resources by its holders and by learning and actually undertaking the investment. Therefore technological uncertainty is intrinsic to the university and entrepreneurs of the spinout as it is them who can actively resolve it internally by undertaking the technology development and finalizing it.

Since technology development is part of the cost of investment, its uncertainty will increase with the volatility of the cost of investment. If an investment has a negative net payoff but its variance of the cost is adequately high, there is still a possibility that it can be economical to invest. Similar to market uncertainty, higher technological uncertainty increases the value of the real option (C). As we have shown earlier in our value function higher option value defers investment in the absence of dividends.

Parallel to Roberts and Weitzman (1981) we argue that the ability to learn about a technology enhances dividends and capture this value in our dividend function by D_L. D_L represents a dividend from learning about a technology by actively investing in it and resolving the uncertainty around it.

We believe that one of the incentives of early technology commercialization through spinout formation is uncertainty resolution of the total investment that is inherent to the investor. Therefore if investing provides information and resolves technological uncertainty, earlier investment in form of a spinout is more likely to occur.

Hypothesis 3: Greater technological uncertainty increases the likelihood of commercializing patents in form of a spinout (exercising the call option)

5.2.2 Uncertainty and the exit decision

As we have pointed out earlier the development of commercially exploitable technology has become increasingly important for the PRO's and universities. Despite a number of success stories of IP commercialization that range from Google to Genentech many of the university spinouts have not been able to survive in the strongly competitive market environment although it is well documented that failure rates of USO's are well below the national average in the USA and European countries (Degroof and Roberts, 2004; AUTM, 2002; UNICO, 2001). Different explanations of firm failure and survival have been proposed by previous research and covered various theoretical angles as we have elaborated in the previous chapter.

In order to survive, new technology firms have to build up an organizational structure and continue the development of their technologies. This task is increasingly difficult when these actions are surrounded by a high degree of market uncertainty. Overcoming these problems has been addressed by previous research including adopting a principle of exclusivity in selecting exchange partners. Podolny (1994) showed that the greater the market uncertainty, the more that organizations engage in exchange relations with those with whom they have transacted in the past and that organizations engage in transactions with those of similar status. Still research on the decision on the termination of investments and the role of real option theory has been theoretically addressed (Dixit and Pindyck, 1994) but empirically mostly neglected by research with the exception of O'Brien and Folta (2009) who are analysing market exit for existing companies in an industry wide setting by focusing on the real option perspective. The theoretical reasoning of real option theory indicates that when an irreversible investment was made and its current net present value is negative, investors will not abandon the investment if the uncertainty regarding future payoffs is large enough as conditions could improve rapidly. This decision rationale can be observed when intensive and irreversible investments are mothballed. This investment strategy can be observed in the mining industry when the price of commodities is very uncertain and waiting rather than completely abandoning the investment could be the decision that yields maximum profits (Dixit and Pindyck, 1994). On the other hand in absence of sunk costs there is no economic rationale for continuing the operation under the occurrence of losses.

New technology based firms and spinouts require initial large investments to initiate and operate which are mostly irreversible and therefore making it a good setting to test the rationale of real option theory on the exit and failure of spinouts. In order to value the abandonment of an investment and its characteristics, real option theory has relied on the study of put options. The owner of the abandonment option has two strategic decisions available namely to early abandon the investment at any point in the option life or wait and continue business as usual. The payoff structure of the abandonment option is similar to the traditional American put option which permits early exercise when the option value is profitable.

The option to abandon gives the owners of the company the right to sell its assets at any time during the option period or close it down to avoid future losses. Exercising the put option entitles the owner to a salvage value (strike price) of the spinout if it is positive. The incremental value from waiting and not exercising the option to shutting down the operation and exercising it, is given by $V = -D + X - P$, where D is the present value of forgone dividends and cash flows for exercising the option early, X the exercise price which describes salvage value and P the put option value. Put option value (P) represents the opportunity cost associated with exercising the option whereas Dividends (D) are potential cash flows only realized if the option is *not* exercised prior expiration date and therefore the spinout not abandoned.

Each of the spinouts in our sample is a high technology start-up that has started to operate based on a unique technological opportunity which we have analysed in the previous chapter. This technology base has growth options embedded which is typical for high technology start ups. The dividend term D refers to the net present value of the main underlying options and therefore can be represented by $D = D_G + D_C - D_D$ where D_G is the value of growth options embedded in the technology base of the company, D_C the cash flow required to sustain the business for the next time period and D_D is the value of the option to defer abandonment. In contrast the decision to terminate a business D_C captures the fact that that the continuation of business is also driven by exogenous factors such as availability of finances and most importantly positive cash flows at the beginning of each continuation period. The optimal abandonment time is when the present value of V reaches a maximum ($\frac{\partial V}{\partial t} = 0$).

The effect of the required cash flow (D_C) on the continuation on the other hand is inversely related to market uncertainty and is the first condition that needs to be met for continuation of business. This factor captures the very important distinction to the firm formation decision in that the continuation of business for a high technology firm is not only secured by the possession of valuable growth options. Spinouts can continue operation only if the cash flow is positive and sufficient finances available. In regimes of very high market uncertainty the uncertainty of cash flows of the high technology company can bring a business to failure although the net present value of all the growth options in possession of the business is positive. Especially under very high market uncertainties this component can be the critical factor if the business can continue operation for one more period. Therefore we would expect that the effect of cash flows under high market uncertainty would overshadow the value of growth options for extremely high levels of market uncertainty and we would expect firm failure rates to increase under very high market uncertainty conditions.

On the other hand we would expect that with increasing market uncertainty the growth and deferment options are dominating the decision and the spinout failure rates will start decreasing as the growth options become more valuable.

This leads us to following non linear hypotheses:

Hypothesis 4: The impact of market uncertainty on exit is nonmonotonic

Hypothesis 5: Market uncertainty will negatively influence the likelihood of spinout failure (exercising the abandonment put option) when uncertainty is low, and positively influence it when uncertainty is high

5.3 Methodology

5.3.1 Sample

The dataset includes data on all inventions and spinouts created by the 78 Max Planck Institutes from 1990 to 2003. The data was acquired directly from the Max Planck technology transfer office (Garching Innovation GmbH) that keeps records of all their commercialization activities. A total population of 811 patents issued by the Max Planck Institutes are examined. The most important advantage of using such a dataset relative to other samples of new ventures is that the TTO's tracks each invention and records every company established to commercialize its IP, which is important to eliminate selection bias.

5.3.2 Analysis

Since our study incorporates a censored dataset of patents with time dependent covariates, we will use Cox regression time dependent analysis to examine the data. The major advantage of using Cox regression is that it does not require an assumption about a particular probability distribution of survival times and the possibility to include time dependent covariates. Time dependent covariates are those that can change their value or impact over the course of observation. This gives us the possibility to predict the likelihood of new firm formation and firm failure on the basis of our specified independent variables and to understand how time influences their impact. The basic model including time dependent co-variates is usually written as:

$$\log h_i(t) = \alpha(t) + \beta_1 x_{i,1}(t) + \ldots + \beta_k x_{i,k}(t)$$

The equation says that the hazard for individual i at time t is a function of a set of a baseline function   at time t and k covariates at time t.

5.4 Variables

5.4.1 Dependent Variables

Firm Formation (INV2USO)

In each year a patent could be licensed or not and the license could be issued to an established firm, or a new firm. Similar to Shane (2001b) we define firm formation (spinout) as occurring in a given year, if the invention was licensed to a for-profit firm that did not exist as a legal entity in the previous year. If the patent is licensed to an established firm, we define this as licensing. If a spinout that is already established comes to get another license from the university in a later year, we will define this occurrence as licensing to an established company. Only patents that are licensed in the year of formation will be considered as leading to firm formation.

Further we will count the number of days from the invention disclosure date to invention commercialization for each single patent in order to be able to test for non proportionality assumption using a time dependent covariate.

Firm Failure (USO2USOTERM)

The technology transfer office keeps records when a firm ceases to exist. Usually this date corresponds to the date the firm legally is declared non existing which is defined as firm failure in this study. Therefore the unit of analysis in this survival analysis is the spinout itself. Further the number of days from the date the firm started to exist until firm closure is counted for each spinout and is used as the time to failure in the survival analysis and for the testing of time dependent covariates related to firm failure. Firms that are still active at the end of the observation period are treated as being censored.

5.4.2 Independent Variables

Real option theory distinguishes between endogenous uncertainties (technological uncertainty) that are intrinsic to the firm and exogenous uncertainties (market uncertainty) which are dependent on the market and where the firm has no influence on. We will account for both types of uncertainties and explore how they affect the likelihood of spinout creation and the timing of innovation commercialization.

Market uncertainty (INV2USO, USO2USOTERM)

The market uncertainty represents the randomness of the external environment and majority of research has measured randomness of demand to account for market uncertainty (e.g. Kulatilaka and Perotti, 1998) as demand impacts prices and therefore determines profitability (Folta and O'Brien, 2004). Since this study measures the uncertainty of the industry segment the patent is in, macroeconomic uncertainty measures (e.g. based on GDP data) will not be considered unlike in the majority of real option literature. This research will rather focus on micro-industry-specific uncertainty. The reason for this is that GDP data is reported in a relatively sporadic manner (quarterly) and it is believed that the decision makers' decision span is more frequent. The patents in this research are subdivided into 5 major technology fields which were classified by the TTO into Mechanical, Medical, Pharma & Biotech, Chemical and Electrical Technology. Therefore, these industry segments will be used to calculate market uncertainty.

The volatilities for each invention were calculated by computing the standard deviation of the industry clusters' daily stock returns. Since the invention disclosure dates were different across inventions, market volatilities for each invention needed to be calculated separately. The standard deviation of the stock market volatilities is specific to the industry subfield and exogenous to the control of individual firms and therefore represents a valid measure for market uncertainty.

It should be noted that stock index data that was used for the volatility calculations was not available for Germany. The available stock indices for Germany were either not dating back for the required time period or some technology industries was not available. Therefore, I have used the FTSE Eurotop300 Indexes that follow the stock prices of these 5 technology clusters for public European companies since 1987 and calculated the volatilities of the stock composite indexes using daily data obtained from DataStream. Since the majority of companies in these emerging technology industries are dependent on worldwide markets it is a valid assumption to use the European wide market uncertainty as it is mainly driven by macro industrial trends. For some industries where a corresponding German stock index could be found, correlations between the German and European Stock indices were calculated and very high correlations coefficients (>95%) were found. This further confirms the previously postulated assumptions.

The next question is how to estimate volatility from this data. A decision maker that has to make a investment decision which value is influenced by volatility (option like contracts) will have to evaluate how the volatility will behave in the future period t during his investment is active. If the investor has estimated (predicted) the volatility correctly over time period t his investment will realize this volatility and this volatility should be used to price an option like contract correctly. This is effectively the volatility we are looking for.

An analogy with the financial markets in which a market to trade future volatility exists can be drawn in order to clarify this even further. The financial markets trade options that have different expiration dates. Each option is quoted a price in the market which is a consensus of multiple buyers and sellers. The market norm is usually to quote volatilities rather than prices because they are interchangeable and can be calculated one from the other. Therefore there is an agreement what the option is worth for a specific expiry (over a specific time period) and a volatility figure is determined by the market. This volatility is called implied market volatility for a specific expiry. This is the number that the whole market expects the option will realize until its expiration and would ultimately be the best estimation of volatility.

Since historical option price data for specific industries does not exist the estimation has to be approached differently. Using a historical estimate of volatility will give the true realized volatility and since volatility is mean reverting, historical volatility will oscillate around the 'true' implied volatility. It was decided therefore to use historical volatility as the approximation of market uncertainty. A more detailed discussion on the robustness [7] of the market uncertainty measure is discussed in chapter 9.1.

Following standard formula was used to calculate the annualized volatility for each invention:

[7] It should be noted here that measuring market uncertainty using the GARCH framework does not significantly alter the results in any of the models

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}\sqrt{252}$$

where σ is the annualized volatility, N the number of daily returns, xi the return in period i and $\bar{x}$ the average return over N periods.

As a reference date the day when the invention was disclosed to the TTO was used for measuring the market uncertainty of the firm formation hypothesis. For the firm failure hypothesis the reference date when the spinout was founded was measured. For each invention the market uncertainty was calculated from the previous daily returns prior to the invention disclosure date (see Folta, 1998). Therefore for each patent a historical 1 year volatility window based on daily stock index return data was obtained. The reason for using the invention disclosure date rather than the date when the patent was granted as the reference date for our calculation is simply because some of the inventions can get commercialized even before the patent was granted.

Technological Uncertainty (INV2USO)

We have previously defined technological uncertainty as the uncertainty regarding the technology development cost and the physical difficulty of completing the investment (Dixit and Pindyck, 1994). One possibility of measuring uncertainty is to ask experts such as technology transfer officers, inventors, and IP lawyers to assess the uncertainty of each technology patent individually at time of publication. Walker and Weber (1984) have utilized such an approach in measuring technological uncertainty in a two dimensional measure as "frequency of expected changes in specifications" and "probability of future technological improvements" measuring technology uncertainty of products for a small number of established firms. In our case this approach would be impracticable due to three reasons. Firstly, the large number of patents we consider in our analysis and the previous approach would limit the sample size drastically since the in depth analysis of a single patent can take several weeks and is very expensive (Markman et al., 2004). Secondly, we are considering uncertainty of already issued patents and it would not be efficient to ask professionals retrospectively about evaluations of patents that are already a couple of years old. Thirdly, technological uncertainty has dynamic characteristics as it fluctuates over time. To account for this problem, we would have to ask professionals if the technological uncertainty changed for each year after patent issuance, which makes this approach implausible. Therefore we will develop a measure which unravels all mentioned disadvantages and does not depend on primary measures.

Before a patent is issued, patent officers determine what previous patents and non patent literature must be cited in a patent by researching prior patents. Each of these citations refers to a specific date when the cited patent was issued. The citations show adjacent technological knowhow and with increasing average age of the citations, the technology field is more explored and more certain. Similar to Lowe (2002) we measure patent specific technological uncertainty (TU) for each patent as the average age of the cited patents (PC_j) and cited non patent literature (NPL_i), where j is the number of the cited patents and i is number of cited non patent literature entries. For the reference date to calculate the average age of patents we use the invention disclosure date. This measure is valid as it provides the technological uncertainty at the time the invention was disclosed and is therefore not a retrospective measure of uncertainty. We define TU as:

$$TU = \frac{\frac{\sum_{j}^{m} PC_j}{m} + \frac{\sum_{i}^{n} NPL_i}{n}}{2}$$

5.4.3 Control Variables

Technical field (INV2USO, USO2USOTERM)

Since patents are more likely to be commercialized in certain technology fields, we will research patents from different technology fields and, we will control for the technology fields the patents are in. Similar to Shane (2001b) we will include dummy variables for mechanical inventions, electrical inventions, chemical inventions and drugs.

Time controls (INV2USO)

We control for effects of time by using a time dummy variable for the period between 1995 and 2003. The reason for the time control is the fact that Max Planck has proactively changed its policy towards spinning out more ventures in 1995. Therefore we expect the highest spinout rates after 1995.

Firm Size (INV2USO, USO2USOTERM)

Research has shown that large firm size in an industry discourages entry since it raises the cost of entry (Audretsch, 1995). We have therefore measured the average firm size per year as the average number of employees per firm in an industry sector. A better measure would be the median of firm size to control for skewness in the distribution. We acknowledge the limitations but the mean was the only available variable existing historically.

Capital Intensity (USO2USOTERM)

We control for the average revenue per company in a given industry. Especially new entrants in highly capital and revenue intensive industries have problems establishing themselves among the competition. We therefore measure the average revenue per company per year in an industry sector and use this variable to control for firm failure.

R&D Intensity (INV2USO, USO2USOTERM)

It was shown that research intensive industries negatively influence new firm entry because large and established firms can achieve larger economies of scope in R&D. We have therefore measured R&D Intensity as a yearly percentage of investments in R&D of the total investments in a given industry.

Capital Availability (INV2USO, USO2USOTERM)

Especially in highly capital intensive industries that are intrinsic to high technology areas in which most spinouts compete, one of the most important moderators of firm formation is capital availability. We will therefore control for industry specific capital availability.

Diverse industries attract capital, e.g. venture capital differently which could lead to a variation of spinout rates due to capital availability. We will therefore assign to each industry class the patent is in the venture capital availability for the year the patent was issued using the Venture Economics database. Similar to Shane (2001b) we will express the capital availability as the venture capital amount spent per year in an industry as a percentage of the average industry asset size.

Age of technology class (INV2USO)

According to Utterback and Abernathy (1975), new companies are more likely to be established when the field of technology is young. We will therefore measure the age of technology class as the number of days between the IPC (international patent class) code was first issued by the patent office and the patent publication date. The difference between age of technology class and technological uncertainty should be elaborated at this point. The age of technology class measures how old the technology class is which is not necessarily related to technological uncertainty. One can assume that an older technology class is also less uncertain but it is still common to observe technological breakthroughs in old technology classes. This is exactly what the technology uncertainty variable tries to capture by analysing the average age of citations rather than the age of technology class. Table 5-2 shows that the correlations of these two variables are relatively low, which strengthens the argument that there is little association between the two variables.

Patent scope (INV2USO)

To control for the patent scope we include Lerner's (1994) measure of patent scope, which is based upon the number of technological classes the patent is categorized into. Patents that are classified into more technological areas are broader in scope according to Lerner (1994) and Shane (2001b) and are more valuable. According to Lerner this measure captures different dimensions of economic importance e.g. firm valuation, likelihood of patent litigation and citations. Therefore it should increase the likelihood of licensing an invention and decrease the likelihood of termination.

Patent Quality (INV2USO)

Previous research has argued that a measure for patent quality can be derived from the fact how many other patents the claims and to how many other patents and non patent literature the patent refers to (Lerner, 1994). We control for patent claims and references since patent value should increase the likelihood of licensing and decrease licensing termination.

Spinout support from technology transfer office (USO2USOTERM)

Several studies have shown that one very important determinant related to the performance of university spinouts are the support structures of the technology transfer office (Shane and Shane, 2002; Saxenian, 1990). Therefore we control for several support occurrences from the technology transfer side. The control variable is coded as 1 if support received and 0 otherwise:

- conceptual support (FLG_SUPP_CONC)
- business plan support (FLG_SUPP_BUSP)
- financial planning support (FLG_SUPP_FINP)
- support by issuing a license to spinout (FLG_SUPP_LICC)
- taking equity in spinout (FLG_SUPP_EQTY)
- after foundation support (FLG_SUPP_AFSP)

Spinout financing (USO2USOTERM)

Resource based theory has shown that firms whose resources are better utilized and that have strong financing structures are more likely to survive especially in harsh and volatile market conditions. Receiving venture funding e.g. was the single most important determinant for the spinout to experience an IPO (Shane and Stuart, 2002). Therefore we control for spinout financing in our study on firm failure. Each spinout can during its lifetime receive financial support which is captured with this variable (1 = support received, 0 otherwise). This support is different from the previous control variable which only refers to support received from the technology transfer office. Financial support is usually received in form of a business loan, government grant or in exchange for an equity stake in the spinout.

Spinout cooperation (USO2USOTERM)

Social ties and network structures have been suggested as an important link to spinout performance. Nicolaou and Birley (2003b) found a link between pre-formation networking and the spinout structure and suggested that the networking ties can influence growth trajectories and performance of the spinout. Further Shane and Stuart (2002) offered empirical evidence of the network-performance relationship, analysing how social capital endowments of the founders affect the likelihood of three critical outcomes of spinouts: attracting venture capital financing, experiencing IPO's and fail. Direct and indirect linkages to investors were found to be constructive to receiving venture funding and reduced the likelihood of spinout failure and that personal networks of founders had a long-term positive effect on spinout performance. Therefore we control for following partnership occurrences during the lifetime of the spinout:

- Max Planck Cooperation (COOP_MPS)
- Industry Cooperation (COOP_INDUSTRY)
- University Cooperation (COOP_UNIVERSITY)

5.5 Results

5.5.1 Spinout formation (INV2USO)

We used a Cox regression analysis to test our hypothesis. Table 5-1 reports the descriptive statistics and Table 5-2 bivariate correlations for the independent variables in the initial regression analysis respectively. The Cox regression models presented in Table 5-3 report how endogenous (market) and exogenous (technological) uncertainty affect the likelihood of new firm formation.

Table 5-1: Descriptive Statistics (INV2USO)

Variables	N	Min	Max	Mean	Std. Dev.
Mechanical	950	0.00	1.00	0.07	0.25
Chemical	950	0.00	1.00	0.28	0.45
Pharma&Bio	950	0.00	1.00	0.42	0.49
Medical	950	0.00	1.00	0.09	0.29
Year Issued (1995-2003)	950	0.00	1.00	0.47	0.50
Patent Quality	950	0.00	613.00	18.82	26.39
Patent Scope	950	0.00	19.00	2.55	2.75
Technology Age	950	0.00	77.33	16.57	13.13
Firm Size	950	71	502	343	118
R&D Intensity	950	250	10884	4573	2785
Capital Availability	950	0.00	352.44	47.42	92.91
Market Uncertainty	950	0.10	0.49	0.21	0.07
Technological Uncertainty	950	-9.13	0.00	-1.20	1.33

As can be seen in Table 5-2, the highest correlation between any two of the independent variables is r = 0.76 between firm size and R&D Intensity control variable. The correlation values imply that multicollinearity problems are not a concern in our analysis. Still our moderately high correlations shown in Table 5-2 indicate that none of the factors that predict firm formation are completely independent which was as well observed by Shane (2001b).

Table 5-2: Correlation Matrix (INV2USO)

	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13
1.	Mechanical	1.00												
2.	Chemical	-0.17	1.00											
3.	Pharma&Bio	-0.23	-0.53	1.00										
4.	Medical	-0.09	-0.20	-0.27	1.00									
5.	Year Issued (1995-2003)	0.03	-0.09	0.09	-0.02	1.00								
6.	Patent Quality	-0.02	0.01	0.08	-0.06	0.05	1.00							
7.	Patent Scope	-0.13	-0.02	0.21	0.00	-0.08	0.16	1.00						
8.	Technology Age	0.14	0.15	-0.27	0.00	-0.03	0.00	-0.08	1.00					
9.	Firm Size	-0.32	0.37	0.50	-0.70	-0.05	0.08	0.17	-0.15	1.00				
10.	R&D Intensity	-0.27	0.72	-0.04	-0.45	0.05	0.04	0.04	-0.02	0.76	1.00			
11.	Capital Availability	-0.09	-0.20	0.37	-0.02	-0.02	0.07	-0.02	-0.04	0.19	0.08	1.00		
12.	Market Uncertainty	0.01	-0.20	-0.06	0.19	-0.05	0.02	-0.11	0.16	-0.34	-0.31	0.30	1.00	
13.	Technological Uncertainty	-0.03	-0.11	0.17	0.01	0.00	0.02	0.07	-0.17	0.06	0.00	0.04	-0.06	1.00

Table 5-3: Cox Regression Analysis for the determinants of firm formation (INV2USO)

Variables	Model 1	Model 2	Model 3
Mechanical	-0.148	-0.028	1.732
Chemical	0.488	0.613	1.986
Pharma & Bio	1.645 ***	0.747	1.924
Medical	1.042 †	1.167	3.593 **
Year Issued (1995-2003)	0.449 *	0.485 *	0.658 **
Patent Quality		0.004 *	0.005 *
Patent Scope		0.003	0.002
Technology Age		-0.034 ***	-0.033 ***
Firm Size		0.004	0.008
R&D Intensity		-0.160	-0.209
Capital Availability		0.003 **	0.002 †
Market Uncertainty			-22.803 *
Market Uncertainty Square			59.978 **
Technological Uncertainty			0.451 **
N	950	950	950
Model X^2	42.2 ***	74.1 ***	90 ***
-2 Log Likelihood	1246 ***	1223 ***	1193 ***

Note: The dataset includes 950 cases and 82 events and two-tailed tests for all variables

† $p < 0.1$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

We provide three models in our analysis and the detailed steps can be found in the Appendix (Chapter 9.4.1). Model 1 presents the base model and predicts the likelihood of firm formation on the basis of the year of patent filing and the industry the spinout is founded in. Overall this model is significant (chi-square = 42.2, $p < 0.001$). As Model 1 shows, the time period when the patent was filed has a positive effect on firm formation. Patents that are filed between 1995 and 2003 had a 0.45 times greater likelihood of firm formation than patents filed before 1995 ($p < 0.05$). This robust pattern of increasing firm formation likelihood is consistent with prior research on entrepreneurship (Gartner and Shane 1995) and also corresponds to the proactive spinout policy of the parent institution. The incidence of spinning out an invention was the lowest for chemical patents ($b = 0.49$, $p = 0.35$) but not statistically significant. Among other industrial controls Bio and Pharmaceutical industry had the strongest relation to spinout formation ($b = 1.65$, $p < 0.001$). It should be noted that the reference industry is the electrical industry, which was omitted from the industry controls to prevent falling into the dummy variable trap, which implies perfect collinearity between the dummy variables.

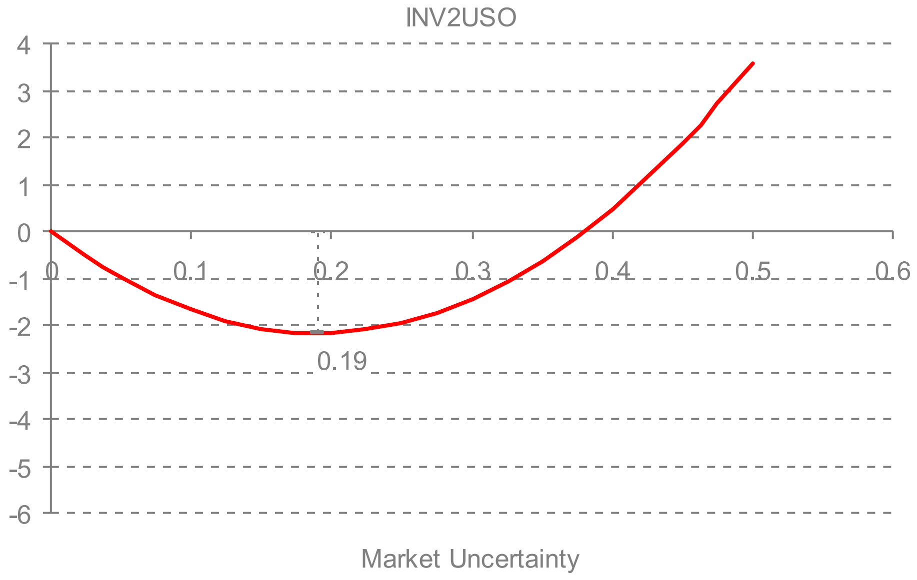
Model 2 reports the baseline model with five additional controls; technology age, venture capital availability, R&D investment intensity, industry firm size and scope of invention. The inclusion of these control variables provides a good fitting model (chi-square = 74.1, $p <0.001$) and all signs are consistent with previous research although some controls are not statistically significant.

Among the control variables technology age had a significant negative relationship ($b = -0.03$, $p <= 0.001$). This result is consistent with Shane (2001b) who showed that age of technology class negatively influences spinout firm formation.

Further R&D intensity decreases the likelihood of new firm formation (although not statistically significant), which is consistent with Scherer (1980) who argued that large firms have competitive advantages over small incumbents in R&D intensive industries because they can more effectively exploit economies of scope in R&D. The availability of venture capital is positively related to spinout occurrence as was expected and highly significant ($b = 0.003$, $p <= 0.01$). Average firm size is not consistent over the models and does not confirm the findings by prior research conducted by Audretsch (1995) who showed that the entry costs in industries with larger firm sizes are higher, making entry for small incumbents less attractive. Furthermore, patent quality is significant ($b = 0.004$, $p <= 0.05$) for all the models and has a positive impact on the incidence of new firm formation (Lerner, 1994).

Model 3 includes market uncertainty, market uncertainty square and technological uncertainty as predictor variables and shows that inclusion of the variables generates a good fitting model (chi-square = 90, $p < 0.001$). These results support the hypotheses 1 and 2. Consistent with hypothesis 1 and 2, the market uncertainty is non monotonic and for low market uncertainty we observe a decreasing likelihood of firm formation and for high market uncertainty a positive relation with firm formation which starts at 38% . Hypothesis 3 is confirmed by Model 3 and shows that the higher technological uncertainty increases likelihood of spinout formation ($b = 0.45$, $p < 0.001$).

Figure 5-1 Nonlinear effect of market uncertainty on firm formation (x-Axis = Market Uncertainty, y-Axis firm formation likelihood)



5.5.2 Spinout failure (USO2USOTERM)

In concordance with our analysis on the spinout entry we use a Cox regression analysis on spinout failure as both model frameworks can be considered as survival models. Descriptive statistics and bivariate correlations for the independent variables are presented in Table 5-4 and Table 5-5 respectively whereas the Cox regression models presented in Table 5-6.

Table 5-4: Descriptive Statistics (USO2USOTERM)

Variables	N	Min	Max	Mean	Std. Dev.
Mechanical	82	0.00	1.00	0.06	0.24
Chemical	82	0.00	1.00	0.12	0.33
Pharma & Bio	82	0.00	1.00	0.62	0.49
Medical	82	0.00	1.00	0.02	0.16
Conceptual Support	82	0.00	1.00	0.50	0.50
Business Plan Support	82	0.00	1.00	0.44	0.50
Financial Planning Support	82	0.00	1.00	0.37	0.49
License Support	82	0.00	1.00	0.30	0.46
Equity Support	82	0.00	1.00	0.30	0.46
External Financing	82	0.00	1.00	0.38	0.49
Industry Cooperation	82	0.00	1.00	0.37	0.49
MPG Cooperation	82	0.00	1.00	0.32	0.47
University Cooperation	82	0.00	1.00	0.09	0.28
Firm Size	82	71	479	364	103
Capital Intensity	82	6116	190539	95374	47723
R&D Intensity	82	250	10443	4509	2097
Capital Availability	82	0	352	97	126
Market Uncertainty	82	0.08	0.36	0.17	0.06

Multicollinearity problems are not a concern as correlation threshold between two variables of 0.8 (Gujarati, 2008) is not breached. The highest observed correlation in Table 5-5 is between R&D investment and average company revenue (0.79).

Table 5-5: Correlation Matrix (USO2USOTERM)

	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1.	Mechanical	1.00																	
2.	Chemical	-0.09	1.00																
3.	Pharma & Bio	-0.33	-0.48	1.00															
4.	Medical	-0.04	-0.06	-0.20	1.00														
5.	Conceptual Support	-0.15	-0.15	0.08	0.00	1.00													
6.	Business Plan Support	-0.02	-0.03	0.13	0.02	0.64	1.00												
7.	Financial Planning Support	0.02	-0.05	0.12	0.04	0.61	0.76	1.00											
8.	Licence Support	0.05	0.16	0.02	-0.10	0.19	0.37	0.43	1.00										
9.	Equity Support	0.16	0.08	0.02	0.07	0.19	0.43	0.49	0.60	1.00									
10.	External Financing	0.12	0.02	0.14	-0.12	0.08	0.27	0.30	0.36	0.63	1.00								
11.	Industry Cooperation	-0.09	0.18	0.12	-0.12	-0.05	0.20	0.21	0.38	0.49	0.56	1.00							
12.	MPS Cooperation	0.05	0.07	0.15	-0.11	-0.05	0.14	0.08	0.35	0.23	0.23	0.14	1.00						
13.	University Cooperation	0.10	0.15	-0.03	-0.05	0.04	0.08	-0.05	0.18	0.08	-0.06	-0.05	-0.02	1.00					
14.	Firm Size	-0.36	0.12	0.77	-0.44	-0.02	0.10	0.06	0.08	0.01	0.14	0.25	0.20	0.06	1.00				
15.	Capital Intensity	-0.27	0.35	0.35	-0.30	0.06	0.13	0.05	0.08	0.02	0.02	0.15	0.12	0.12	0.68	1.00			
16.	R&D Intensity	-0.32	0.51	0.34	-0.28	-0.05	0.08	-0.01	0.10	-0.06	0.00	0.22	0.19	0.13	0.79	0.70	1.00		
17.	Capital Availability	-0.17	-0.29	0.50	-0.11	0.23	0.06	0.10	-0.06	-0.05	0.02	0.01	0.00	0.15	0.41	0.09	0.33	1.00	
18.	Market Uncertainty	-0.09	-0.26	-0.21	0.05	0.24	-0.01	-0.06	-0.11	-0.14	-0.19	-0.30	-0.11	-0.04	-0.39	-0.40	-0.28	0.24	1.00

Similar to the previous chapter we provide the statistical model in three blocks to check for the stability of the results. The main model is shown in Table 5-6 and the detailed modelling steps can be seen in the Appendix. Model 1 presents the base model and predicts the likelihood of firm failure on the basis of the industry the spinout is founded in. Overall this model is not significant and firm failure does not differ across industries in our sample. This finding is not consistent with Shane and Nerkar (2003). Their analysis showed that spinout failure across industries is more likely in the electronics industry.

Model 2 shows the baseline model with twelve additional controls including: technology transfer support structures, venture financing received, cooperation, firm size, R&D intensity and capital intensity. Inclusion of the additional control variables results in a good fitting model (chi-square = 60.4, $p < 0.001$). Interestingly none of the technology transfer support variables is significant and it seems that the technology transfer office cannot 'save' the spinout from failure. Still the technology transfer office activities can be very beneficial to the performance of its incumbents as has been supported by previous research. Still the one dimensional performance measure of firm failure which is the subject of this analysis cannot be mediated by any support mechanisms of the TTO in our data sample.

External financial support seems to be negatively correlated to firm failure which is to be expected. Spinouts that receive financial help are 2.1 times less likely to fail ($p <= 0.05$).

On the other hand cooperation with industry as well as cooperation with other universities decreases the likelihood of failure by 3.1 and 2.6 times respectively and both are strongly significant ($p<=0.01$). Surprisingly cooperation with parent institutions of the Max Planck Society does not significantly influence spinout failure.

Among the other control variables R&D intensity positively influences spinout failure as was expected ($b = 0.98$, $p <= 0.05$). Furthermore the model shows that availability of venture capital in an industry increases firm failure ($b = 0.006$, $p <= 0.05$).

Model 3 includes market uncertainty and market uncertainty square as predictor variables and shows that inclusion of the variables generates a good fitting model (chi-square = 64.6, $p < 0.05$). These results support the hypotheses 4 and 5. Consistent with hypothesis 4 and 5, the market uncertainty is non monotonic and for low market uncertainty we observe a decreasing likelihood of firm failure and for high market uncertainty a positive relation with firm failure formation (see Figure 5-2), which starts at 44%.

Figure 5-2 Nonlinear effect of market uncertainty on firm failure (x-Axis = Market Uncertainty, y-Axis firm failure likelihood)

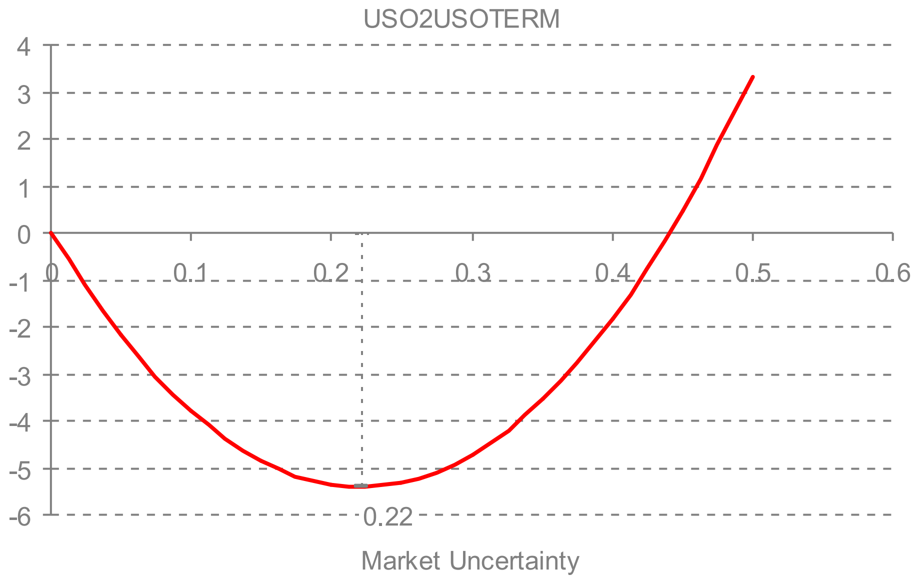


Table 5-6: Cox Regression Analysis for the determinants of firm failure (USO2USOTERM)

Variables	**Model 1**	**Model 2**	**Model 3**
Mechanical	-0.825	-0.379	0.162
Chemical	-1.331	-2.111	2.141
Pharma & Bio	0.22	3.926	5.124
Medical	-12.19	-17.43	-16.68
Conceptual Support		0.820	0.786
Business Plan Support		-0.640	-0.433
Financial Planning Support		0.288	-0.044
Licence Support		-0.765	-0.560
Equity Support		1.151	1.871
External Financing		-2.090 *	-2.923 **
University Cooperation		-3.085 *	-3.446 *
Industry Cooperation		-2.595 *	-3.091 **
MPG Cooperation		-0.198	-0.301
Firm Size		-0.037	-0.032
R&D Intensity		0.981 *	1.021 *
Capital Intensity		-0.005	-0.005
Capital Availability		0.006 *	0.007 **
Market Uncertainty			-49.14 **
Market Uncertainty Square			111.5 **
N	82	82	82
Model	4.93	60.4 ***	64.6 *
-2 Log Likelihood	202	144 ***	137 ***

Note: The dataset includes 82 cases and 26 events and two-tailed tests for all variables

† $p < 0.1$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

5.6 Discussion

We have examined data on the population of Max Planck inventions over the 1990 to 2003 period. To build a robust model of firm formation and firm failure we have included several control variables that previous research has shown to be significantly influencing the dependent variables. Overall we found that market uncertainty is non monotonic in both, the firm formation as well as the firm failure model. Further we have shown that technological uncertainty influences the likelihood that an invention will be commercialized through firm formation.

We have found that market uncertainty has a nonlinear relation to firm formation and that higher uncertainty increases the likelihood of firm formation and that lower market uncertainty decreases it. Further greater technological uncertainty increases the likelihood of commercializing patents in form of a spinout. Looking at the spinout failure model we found that for increasing and moderate levels of market uncertainty the firm failure rates decrease whereas spinout failure is more likely to occur under very higher market uncertainty.

Our design for both models resembles the design of Shane (2001a) using a Cox regression (survival analysis) for both dependent variables (firm formation and firm failure) and assures the validity of the results due to following characteristics. Firstly our design includes the complete population of patents as well as spinouts issued by our target institution and therefore avoids sample selection bias. Furthermore the study on firm formation examines patents and inventions that are simultaneously at risk of being exploited through firm formation as well as being licensed in by established firms, where both commercialization forms are mutually exclusive in our sample. Secondly we are examining patents and spinouts from a single research institution, where the opportunities as well as the entrepreneurs who exploit them have homogenous characteristics. This reduces the bias of the heterogeneous characteristics of entrepreneurs that are involved in firm formation as well as firm failure.

The implications of this research make a clear contribution to the literature by being the first to empirically investigate different forms of uncertainty not only on the entry of new high technology firms but also on their failure which we will analyse in more detail in the next two chapters.

5.6.1 Firm formation

Looking at the firm formation in more detail our results show that high technological uncertainty increases the likelihood of entry and that firm formation is negatively correlated for low market uncertainty and positively for high market uncertainty. We therefore demonstrate that option value and ultimately firm entry likelihood (exercise decision) and entry timing changes with the uncertainty regime the technological opportunity is found in. For example as market uncertainty is dynamic and exogenous and changes in industries over time we expect the firm entry rates to follow this dynamic behaviour and behave accordingly. Technological uncertainty on the other hand is endogenous and is intrinsic to the technology regime it is found in. It does not show dynamic behaviour like market uncertainty and can only be resolved by subsequent investment and research. These findings add further support that two different classes of uncertainty are underlying the complex relationship between option value and its exercise. Further our findings confirm results of previous studies that found a nonlinear relation between new firm formation and exogenous uncertainty. As we have shown in knowledge intensive industries (which were the focus of our analysis) compound growth options might dominate investment value leading to our finding that higher market uncertainty increases likelihood of new firm formation. On the other hand in industries with small or non existing growth options, exogenous uncertainty is expected to be a deterrent of new firm entry.

Hypothesis one relies on the same theory and reasoning deducting the hypothesis as the work of Folta and O'Brien. The main difference and contribution of hypothesis one is that it explains a different phenomenon. Whereas Folta and O'Brien focus on the decision by existing firms to enter new industries, hypothesis one focuses on the individual invention and technology level and explains new firm formation from new entrepreneurs. It uses therefore a different setting and completely different dataset. It follows each invention and opportunity and examines its occurrence rather than looking on firm wide level. This enables us to control for invention specific variables and as well extend real option theory to endogenous variables such as technological uncertainty which cannot be accomplished with the approach by Folta and O'Brien as their data choice does not allow this. Further, decision heuristics can be different for decisions coming from large corporations and individual entrepreneurs. Hypothesis one reaffirms and strengthens real option reasoning as it extends the work on Folta and O'Brien (2004) in a way that it shows that it is not only applicable in corporate entrepreneurship but as well on the individual entrepreneurship level. A similar approach towards explaining entrepreneurial entry was done by Shane (2001a) who has followed each invention individually but has not focused on real options and on the variables used in this study. Further the thesis extends the work by Shane (2001a) and Ziedonis (2007) as it is using a competing risk model to explain competing risks of technology commercialization (see Chapter 6.6).

The results are important mainly to two streams of research on new firm formation. One of the streams analyses the market structure of an industry to understand firm formation (Audretsch, 1995) but does not provide an extensive overview and empirical evidence how market uncertainty influences it. Further, we contribute to another stream of research that looks at the technology level and tries to identify technology specific characteristics that have effect on firm entry (Shane, 2001b).

The results should be particularly interesting to scholars of strategic management who study the challenge established firms are facing with new entrants. Our framework provides evidence under what circumstances of uncertainty existing firms are most likely to be challenged by new firms. In general it provides a framework for strategic management scholars to understand under which circumstances competition with new entrants arises.

Future work should try to validate these findings by extending the research to different industry sectors we have not included in our sample. While we have aggregated market data for 5 industries future research could include a greater detail of industry sub levels and depth. We should note that this extension can only have effect on the findings including market uncertainty, since technological uncertainty is market independent. Further research could also be extended to different or a larger number of institutions to generalize the findings since we have analyzed this behaviour based on the technological innovations of only one large research institution located in Europe.

Our research has primarily focused on the market-wide factors that influence the value of real options. An area for further research could be to investigate factors on the institution-level that might influence the value of technological options they plan to pursue. Such institution-level factors may help to understand how different institutions are coping with exogenous and endogenous uncertainty in order to optimize their technology commercialization outcomes.

5.6.2 Firm Failure

In this chapter we have examined the effects of market uncertainty on the likelihood of firm failure for university start-up companies. Our unique dataset consists of 82 companies that were created from research based in the Max Planck Society between 1990 and 2003. We showed that market uncertainty has a non monotonic effect on firm failure and that in market environments with very high market uncertainty firm failure is more likely whereas relatively stable markets decrease firm failure rates.

Previous research has shown that the likelihood of new firm survival depends on the radicalness of technologies they exploit especially when they operate and compete in fragmented industries (Shane and Nerkar, 2003).

Apart from radical technologies newly formed firms from research institutions usually operate in uncertain markets and previous research has not addressed how it affects firm failure of newly established firms. Ghosal (2002) has shown in an industry wide study on 267 manufacturing US industries that especially small companies are susceptible to the influences of market uncertainty whereas big companies seem not to be affected. He showed that increasing uncertainty is detrimental for survival of small companies but treated uncertainty as monotonic. Our study is consistent with these findings for higher ranges of uncertainty. We have shown that low uncertainty increases the survival of high technology companies when it is smaller than 44 % (quadratic equation solved for model 3 in

Table 5-7). Since we have shown that uncertainty is non monotonic, we showed that uncertainty values above 44% seem to be detrimental for high technology companies.

Therefore our study is consistent with previous findings and complements them since it shows that uncertainty has a non monotonic impact on high technology firm survival rates.

5.6.3 Interaction Effects

In addition to the previous results we have tested the dependent variables for interaction effects between themselves as well as the control variables for completeness of the analysis. The details of the analysis for spinout formation can be found in chapter 9.4.2 whereas the chapter 9.4.4 contains the analysis for the interaction effects of spinout failure.

Only one significant interaction effect is discovered for spinout formation and that is between the market uncertainty and capital availability.

Table 5-7 Summary of interaction effects for the firm formation model

Interactions	**Coefficient**
Market Uncertainty * Capital Availability	-0.378 †
Market Uncertainty Square * Capital Availability	0.779 †

Legend
† $p < 0.1$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

The mediating effect of market uncertainty and capital availability can be interpreted as follows:

- In more certain markets capital availability attenuates the effects of market uncertainty on firm formation whereas in uncertain markets capital availability accentuates the effects of market uncertainty on spinout formation

The interaction model for the firm failure model was performed but no significant interaction effects were found between market uncertainty and the other independent variables.

6 The lifecycle of a license under market and technological uncertainty

6.1 Introduction

The rise of university and public research organization (PRO) commercial efforts in the recent years lead to a steady increase in patenting and licensing that almost tripled over the last decade (AUTM, 2002). This growth shows the success in technology transfer and suggests the increasing importance of universities and PRO's in technology innovation. A major shift towards support of university and PRO commercialization efforts came over the last two decades from incentive structures initiated by several governments that have recognised the value and started to develop support structures. Major policy changes such as the Bayh Dole Act, but also other supporting policies, such as promoting cooperative R&D, patent policy to expand government technology, relaxing antitrust regulations, developing cooperative research centres and altering guidelines for disposition of government owned intellectual property (Bozeman, 2000) have supported the orientation towards commercialization of innovations created in universities and PRO's. This phenomenon can be observed on an international level and has inspired a recent increase of research interest on the drivers of university IP commercialization with one of the main vehicle of commercialization being licensing contracts. Universities and PRO's typically require faculty, staff and students to file invention disclosures whenever a new invention was generated. Further they retain the rights to these inventions. Technology transfer offices (TTO) usually review these disclosures and decide whether to file for a patent and subsequently with which commercialization approach to proceed. Patenting is one of the most obvious and common ways of protecting a submitted invention. Since the scope of protection for patents is not equally effective across technological fields and the fact that an innovation must be must be novel, non-obvious and valuable (see Chapter 4) to be patentable, only a proportion of all filed inventions are patented. The role of the TTO is therefore to decide on the lifecycle of the invention disclosure by maximizing commercial and strategic value for the university or PRO. In the majority of cases the TTO decides to licence the invention to an existing company and/ or cooperation partner. It therefore provides a good setting of understanding the economics and determinants of licensing, which is one of the most common and most important inter firm contractual agreements especially in high technology industries (Grindley and Teece, 1997).

However licensing activity has traditionally been a subject of theoretical enquiry where empirics were extremely rare (Anand and Khanna, 2000). Theoretical angles explaining licensing contracts can be found in industrial organization theory and game theory that broadly cover following three research fields (Anand and Khanna, 2000). (1) Relationship between industry structure and choice of licensee (Arrow, 1962), (2) value creation of licence contract between licensor and licensee (Kamien and Tauman, 1986), (3) likelihood of ex ante or ex post licensing and relationship between sequential innovations and licensing strategies (Shapiro, 1985). Recently some studies have viewed licensing from the real option perspective and analysed impact on the investment and financing of technology investment (Kulatilaka and Lin, 2006).

A small number of studies have analysed the licensing phenomenon from an empirical perspective with the main ones being Anand and Khanna (2000) who elaborated cross industry differences in licensing contracts, Grindley and Teece (1997) who have analysed licensing practises in particular industries and Caves et al. (1987) who have surveyed licensors and licensees on their licensing practises in a small sample survey. Studies combining theory with strong empirics are rare with the two main exceptions being Ziedonis (2007) and Dechenaux et al. (2003). Our study aims to bridge this gap and comprehends current research with following novelties:

Especially the highly uncertain underlying technology of university inventions requires substantial development under volatile market conditions to achieve commercial success therefore making uncertainty one of the main influences of commercialization success. Recent research has used the theoretical lens of real option theory mostly to value R&D projects under uncertainty and to highlight the additional value uncertainty can bring to an option value. A relatively small fraction of research studied the influence of uncertainty on commercialization activities and its timing, to which high technology inventions are particularly exposed (Dechenaux et al., 2003).

We will fill the gap and explore under what conditions of uncertainty, predominantly to be found in early stage technologies and research intensive industries, inventions get commercialized. In particular, we will examine the effects of exogenous (market) as well as endogenous (technology) uncertainty on innovations and analyze how they are affected by passage of time. Therefore, our study will be the first to study both, the influence of exogenous (market uncertainty) and endogenous uncertainty (technological uncertainty) on licensing activities.

Secondly, we view the commercialization decision under a new theoretical angle and approach the research questions by grounding our findings on the foundations of real option theory (ROT) in order to consolidate different forms of uncertainty and optimal decision timing into one theoretical framework. Real options framework can add new insight towards decision making, namely the understanding of entry timing of decisions and investments under uncertainty. Particularly in this case ROT will be used to understand how uncertainty affects the lifecycle of a licence from its inception to termination.

Lastly, although a small number of studies have utilized quantitative and empirical approaches towards university commercialization activities most of them relied on a single research institution in the US. Our study is the first to explore a quantitative dataset of university research activities outside the US.

The following section provides a brief introduction into the real options literature and develops relevant hypotheses. Chapter 6.3 describes the sample, explains the empirical methodology, and presents the variables. Section 6.4 reports the model and empirical findings. Finally, Chapter 6.5 and discusses implications and provides a conclusion of this part of our research.

6.2 Theory Development and Hypothesis

Real options are derived from financial options which give the option holder the right to buy (call option) or sell (put option) a valuable asset traded in the financial markets for a given price. Similar to their financial counterparts, real options give the option holder the right to obtain a 'real' investment for a given price that usually corresponds to the cost of the investment. The value of the option corresponds to the difference between the uncertain payoff and uncertain investment cost and can never be smaller than zero. Therefore the option holder possesses the right, but not the obligation, to exercise the investment, should the total payoff look attractive. This protection against the downside risk can only lead to the loss of the right rather than the whole investment itself assuming the investor has not exercised the option and committed to the irreversible investment.

The main prediction of real option theory is that greater uncertainty increases the value of the option since the upside earnings potential is not limited whereas the downside risk is. As mentioned earlier, different forms of uncertainty influence the value of a real option. Two major forms of uncertainty are pertinent in the real options literature (exogenous and endogenous) that affects the value and the decision regarding valuation and execution of real option contracts (Dixit and Pindyck, 1994; Folta, 1998). Exogenous uncertainty, usually referred to as market uncertainty, is affected by external market forces and can only be resolved through waiting. Further the holder of the option does not have any effect on this form of uncertainty and resolution is independent of actions of the option holder. Endogenous uncertainty on the other hand refers to uncertainties intrinsic to the investment where the investor can have influence on its resolution. Dixit and Pindyck (1994) have shown that endogenous uncertainty can only be resolved by active investment of the option holder and usually encourages early and sequential investment.

Each invention created by university researchers passes different phases before it can be absorbed in a commercial setting which we refer to as the pre and post licence phase. The process and pre-license phase starts with the invention being disclosed to the technology transfer office by a university scientist or a research group. Once an invention is licensed, we consider that the same invention is in the post licence phase.

The TTO can decide what to do with the university invention but the basic two ways of commercialization are a) licensing the invention to an industry partner or b) exploiting the technology themselves by investing in the technology and e.g. creating a university spinout. Basically MPS uses license agreements to provide commercial usage rights of their inventions, patents, technical know-how or software against payment. The majority of licences are patent licences meaning that MPS will not sue a counterparty that infringes MPS's patents on the licensed technology. During the licensing agreement the limitation is usually agreed upon between licensor and licensee and refers to limitations of usage to specific technology fields or territories. Further the sponsors of research (e.g. government) can guarantee themselves to exploit the technology in a limited fashion. In an additional agreement the licensee might lock in additional assistance in areas such as training, technology transfer, consulting and further development of the underlying product.

A common process a licensee passes through before committing to a licensing contract:

- conducting due diligence on the underlying technology
- deciding on licensing terms with the TTO

The licensing terms usually encompass:

- exclusive vs. non exclusive licence
- territory and field limitations if any
- amount and form of payment
- milestones for development
- additional TTO assistance and support

License revenues exist in form of milestone payments, unique upfront payments as well as royalties on inventions once they have commercial value. The royalty payments can take a variety of forms. Some of the most common are fixed per unit royalties, royalties as percentage of revenue streams as well as royalties that scale with the success of technology usage. The licence can be up to the life of the underlying patent but is usually defined for a period of time. The termination of a licence is usually negotiated with the TTO at will which enables the licensee with the right to terminate the license at some period of advance notice. The TTO possesses as well the right to terminate the licence if the licensee violates the licensing terms such as not paying the royalties or milestone payments.

License agreements as previously mentioned are negotiated, locked in and supervised by the patent and license managers as well as lawyers of the TTO. If a licensee is found, licensing can bring in a stable revenue flow in the short term. However, it can be more profitable over the long term for the institution by taking equity stake in form of a spinout in lieu of licensing fees if the technology proves to be successful. Generally a greater risk pays potentially a greater reward. The difficulty lies in the fact that the decision makers operate under ubiquitous uncertainty regarding market conditions as well as the technology itself when trying to make this decision (assuming both options can be pursued). Especially in high technology industries where dynamic and volatile markets dominate the commercialization potential of new technologies and the technologies itself underlie high uncertainties regarding their feasibility it is important to understand how the markets govern the commercialization of innovations.

University inventions have option like characteristics as the option holder has a limited downside risk but upside potential to exploit it. If the technology turns out to be technologically not feasible and problematical or the market demand is not favourable, the option holder can decide to abandon the licence and other subsequent investments. Moreover the licence on the invention is timely bounded as the monopoly profits based on the invention expires after a fixed amount of time (usually 20 years). Further other competitors in the same technology domain may reduce the shelf life of the patent by inventing around or creating substitutes for the licensed invention. Another important characteristic is that the invention value is highly susceptible to uncertainty regarding its market value as well as its technical feasibility. Another important characteristic is that the underlying investment is irreversible.

PRO's and universities are involved in cutting edge research and pioneering development of new ingenious technologies. These technologies have potential to be commercially valuable but are in very early development phases making them susceptible to high technological as well as market uncertainty. Obtaining a license allows the licensee to gain early access to the underlying technologies but requires further investments in technology development if the commercial phase is to be achieved. We consider licenses as an opportunity to invest in a first generation high tech product that are in real option terms analogous to an compound option (options on options) for the licensee (Trigeorgis, 1993). This type of option gives the licensee the opportunity to stage investments with the ability to discontinue investment and abandon the licence in the event that the technology seems not feasible or unfavourable information is uncovered during the investment period. The subsequent options that the compound option holder is entitled to can be seen as growth options that give the licensee the option to expand in a technology field.

Following section provides a framework that will be used to identify and clarify how different forms of uncertainty influence the lifecycle of the invention in the pre and post-licensing phases especially in research intensive industries where uncertainty can have large impact on the decision making process.

6.2.1 Effects of Uncertainty on Licensing and Licensing Termination

Uncertainty is usually feared by investors as it diminishes the predictability of the profit (Dixit and Pindyck, 1994). Still uncertainty can create opportunities when it is properly understood (Amram and Kulatilaka, 1999) and real option theory tries to understand the effects of uncertainty on optimal investment decision making giving uncertainty a value during the decision process (Dixit and Pindyck, 1994).

It was stated earlier that market uncertainty is referred to as a form of exogenous uncertainty and cannot be affected by actions of the option holder as it is determined by the market. Option theory tells us that the value of the option increases with increasing uncertainty regarding the underlying asset. Similar to a financial option, options on new technologies become more valuable when market uncertainty is high, that is when the future value of the underlying asset (e.g. future cash flows from the licence) or the investment cost itself fluctuates strongly. Innovation literature has observed the fact that technology value is proportional to underlying demand's potential variance and uncertainty (McGrath, 1997).

On the other hand waiting for the uncertainty to resolve and gain new information regarding its value through time has a value which in ROT literature is regarded as the option to delay or defer. This delay of action and waiting to receive new information influences the attractiveness of the investment as well as the decision timing of the option holder when to exercise the option and commit to the irreversible investment. Under the option framework when dividends (opportunity costs of not committing oneself to the investment and exercising the option) are not existing it is always optimal to delay exercising the call option as long as possible if dividends are not present (for proofs see Miller and Folta, 2003 or Dixit and Pindyck (1994) who showed that it is never optimal to exercise an American option prior expiration date).

Licences on the other hand present a compound option for the licensee. These are options to expand current operations that are of considerable strategic importance and enable the exploitation of future opportunities. A good example is the pharmaceutical and biotech license that introduces a new technology resulting in a new product and future growth opportunities. A license is an early stage technology needs to pass though clinical phase I study, clinical II study, clinical III study and an FDA regulatory review. Even when the phases were successfully developed there is substantial uncertainty about the potential cash flows and revenues of the technology. A licensing agreement for an early technology therefore transfers the development and commercialization risk to the licensee who has the flexibility to decide when to commit to the next step of development and investment.

Exploiting the licence usually is a sequential process and each required investment can be seen as link in the chain of interrelated investment projects. The ultimate value may not be directly measured from cash flows of the license itself but rather from unlocking future growth opportunities (growth options). These growth options can be of strategic nature such as developing a new product to preempt competition, accessing or expanding to new markets and strengthening firms' core capabilities and positioning (Trigeorgis, 1993). The value of waiting and postponing licensing the invention is small relative to the value depreciation of the growth options across time (Folta and O'Brien, 2004). Since the value of the options increases with the market uncertainty regime, the licensee is interested in getting access to the underlying growth options as soon as possible and therefore it is expected that under higher market uncertainty the licensee of a high technology that is sensitive to uncertainty will purchase it earlier rather than later. Further universities and public research institutions have usually a broad spectrum of research activities and markets the inventions might be valuable for. Exact understanding of how these markets work and function is a prerequisite of understanding the commercialization potential of the invention. Lack of industry experience and market understanding is especially accentuated when high market uncertainty persists. In these cases the consequences of market uncertainty might better be understood by industry professionals rather than the research institution itself who decides to sell the invention in form of a licence rather than exploit it themselves in form of a spinout. Therefore there is an increased preference for licensing when uncertainty gets higher.

However at some extreme high levels of uncertainty, the costs of developing the technology overwhelm the likelihood of extracting any license and so it does not occur.

These arguments lead us to following hypothesis:

Hypothesis 1: The impact of market uncertainty on selling patents in form of a license is nonmonotonic

Hypothesis 2: Market uncertainty will positively influence the likelihood of selling patents in form of a license when uncertainty is low and negatively influence it when uncertainty is high

The technology licensed from a PRO is usually novel piece of technology for the licensee. The learning process, experience, potential by products gained during the development and exploitation of the licence may serve as a catalyst for improved future generations of that product or even advances in other areas. Further the experience and learning process during exploitation of a novel technology and license can reinforce the licensees' competitive advantage. All these benefits are not possible before the licensee commits to make the initial investment and purchase the license.

It was pointed out earlier that inventions of research institutions and universities stem mostly from basic research and need further technological development before the technology can be ready for commercialization. These technologies have a risk and uncertainty associated with them which are referred to as endogenous uncertainty or technological uncertainty. This form of uncertainty is resolved by active involvement by the firm, and encourages early and sequential investment (Dixit and Pindyck, 1994). Technological uncertainty is a technological bottleneck that the invention can have commercial use whereas market uncertainty determines the market value of the technology once it is developed and technological uncertainty resolved. For this reason technological uncertainty is intrinsic to the option holder as it is them who can actively resolve it internally by undertaking the technology development and investing time and resources.

From the real option perspective higher technological uncertainty incentivises early and incremental investment and increases the probability that the license is purchased. Another important point to be made is that the knowledge intrinsic to an early stage technology is best understood by the scientists themselves (technology creators) who possess knowledge which further investments and resources are needed for the inventions' technical feasibility. The ability to evaluate external information and the ability to utilize external information was observed by Arora and Gambardella (1994) as two dimensions of a firm's absorptive capacity that affect a firm's likelihood to enter in technological collaborations in different ways. External buyers (licensees) of technologies have limited access to this form of tacit knowledge and are reluctant to buy a technology that is technologically highly uncertain as they do not possess the knowledge to estimate how much effort and resources are needed and have problems evaluating it. This risk is usually mitigated by the fact that the TTO offers support of technology transfer to the licensee.

Therefore if investing provides information and resolves technological uncertainty like e.g. taking out a licensing contract, higher technological uncertainty increases the probability of licensing the invention. This leads us to following hypothesis.

Hypothesis 3: Greater technological uncertainty increases the likelihood of selling patents in form of a licence (pre-licensing phase)

One important question raised by strategic investment literature addresses the timing of entering new markets of existing under competition. Companies that develop new products face often the dilemma of early versus delayed entry. Both can be beneficial in a sense that early entry can discourage other competitors from market entry by profiting from early mover advantages whereas delaying entry and waiting for market uncertainty to resolve can lead to more certain and predictable investments. When the new market turns out to be strong, delaying investments can be the suboptimal strategy since gaining a strong market position can than be more difficult.

Preemption refers to the possibility of other parties entering the same market and can be viewed as possible strategic investments which from the option perspective reduce the value of competitor's dividends as well as the value of the competitors' real options (Miller and Folta, 2002). A call option on a monopoly position is analogous to a call on a stock paying a constant dividend whereas under competition the dividend payout decreases as rivals enter the market (Miller and Folta, 2002). Therefore option value (C) in a market that faces high threat of preemption is lower than in a market where there is no threat of preemption (current dividends are reduced), which represents the loss of market share in the next period due to competitive preemption. Especially, entrants in new technology fields face the threat of preemption as existing companies try to secure their position through patenting and commercializing new technologies by increasing the cost of subsequent entry of rivals. As we have shown, technological areas with high threat of preemption can indicate a strongly contested technological field, mostly dominated by incumbents, which can be unattractive to new entrants. Consequently, the higher the risk that a real option will be exploited by competitors (e.g. through existing companies or other start-ups), the less likely will be the exercise of the option. This leads us to following hypothesis:

Hypothesis 4: High threat of preemption negatively influences the likelihood that an invention will be licensed (pre-licensing phase)

In the previous chapters we have considered an invention as an option to commercialize it either by selling the invention in form of a license or by exercising it in form of a spinout. Once the invention is sold the licensees hold themselves an option to commercialize the underlying IP. The licensee is bound through one or more of the following alternatives to the licensor such as milestone payments, unique upfront payments as well as royalties on inventions once it has reached commercial value. If the commercial potential of the license turns out to be less than expected and therefore less than the cost needed to maintain it, the licensor can terminate the agreement and decide not to continue paying the costs for the license. Unlike in the spinout case the sunk cost in exploiting the license is much smaller and the sensitivity of uncertainty on cash flows from the license much smaller since the project can be mothballed whereas the spinout cannot. This leads to the fact that the decision is mostly governed by the value of the option rather than external factors. As we have pointed out in earlier chapters an option value increases with the market uncertainty regime it is found in. In relatively certain markets the value of the option can be relatively small compared to the investment needed for its continuation. Further the value is much easier to estimate in these market conditions. This would lead that in low uncertainty conditions the option would be terminated as soon as the licensee realizes that it cannot be a commercial success whereas in regimes of high levels of market uncertainty it is preferable for the licensee to hold an option as it increases in value. Therefore we would expect that under very high market uncertainty the licensee would not abandon his license and keep it.

This leads us to following hypothesis:

Hypothesis 5: The impact of market uncertainty on licensing termination is nonmonotonic

Hypothesis 6: Market uncertainty will positively influence the likelihood of terminating licenses when uncertainty is low, and negatively influence it when uncertainty is high

A licence provides the firm with the opportunity to generate cash flows in the future on the underlying technology. The firm however also has the opportunity to "put" the project back and abandon the investment permanently. This is usually done when the continuation value of the project is smaller than the value of abandoning it. If events unfold such that market demand for the new product is weak and not sufficient for the new product to be profitable, the firm can with a prior notice terminate the project, halt development and technology exploitation and stop paying license fees. In such a case the option to abandon the license can be framed as an American put option since it can be exercised at any point in time. The licensing firm has the right, but not the obligation to terminate the project and if possible sell off, write off or reuse the project's assets in another setting. The firm will in this case exercise the put option and abandon the project. On the other side if demand turns out to be strong and the technology development successful, the licensee will allow its put option to expire, and will continue to develop further and eventually market the new technology. The value of each option is increasing with uncertainty according to real option theory. Therefore the value of the abandonment option increases with both market and technological uncertainty. However unlike a growth option, the option to abandon does not contain hidden value that might influence the exercise timing of the option. Dixit and Pindyck (1994) have shown analytically that uncertainty over future demand increases the firms' zone of inaction for options to abandon and stop an investment. Therefore we expect the licensee to postpone abandonment under high market uncertainty and wait. Only when the demand structure is certain and the licensee expects a negative demand for the technology they will abandon the license and development of the technology as was explained in the previous hypothesis. For technological uncertainty on the other hand there is no value in waiting since it can be only resolved by active investment of the licensee. Especially externally developed technologies that are licensed have a additional risk as they are not developed in house and expertise and knowledge have to be transferred to the licensor. Therefore high technological uncertainty will always lead to a higher likelihood of license termination. This leads us to following hypothesis:

Hypothesis 7: Greater technological uncertainty increases the likelihood of abandoning and terminating the licence by the licensee (post-licensing phase)

6.3 Methodology

6.3.1 Sample

The dataset for this study comes from unpublished records of the technology transfer office of the Max Planck institution that keeps records of all their commercialization activities. The data includes all patented inventions by the MPS faculty, staff and students from 1990 to 2003.

MPS practices a licensing process that includes different ways of obtaining a license. A firm can either agree a non exclusive license, an exclusive license, an option on an exclusive license and an option on a non exclusive license. The term exclusive grants the potential licensee an exclusive right either (in an option on a license contract) to use information disclosed by the university to determine the technological and commercial viability of the invention or (in a license contract) to have rights to commercialize the university invention and generate cash flows from it. We consider an option on a license as a compound option (option on option) and exclude it from our analysis. Typically the firm pays up-front fees, royalty payments, and/or minimum royalties fee for obtaining the license.

A complete population of 1123 invention disclosures are examined for the prelicensing phase out of which 484 were licensed out to the industry (including exclusive, nonexclusive and licence options). The postlicensing phase contains data on all 484 exclusive and nonexclusive licensed patents out of which 186 licences were terminated prematurely. A major advantage of this dataset relative to other samples of is that the TTO's tracks each invention and records every licence activity and commercialization effort of its IP, which is important to eliminate selection bias.

6.3.2 Analysis

Cox regression time dependent is the first analysis of choice in our case since our study incorporates a censored dataset of patents with time dependent covariates. Several advantages exist compared to other regression methods with the major advantage of that not requiring an assumption about a particular probability distribution of survival times. Further it allows the inclusion of time dependent covariates. Time dependent covariates are those that can change their value or impact over the course of observation. This gives us the possibility to predict the likelihood of new firm formation on the basis of our specified independent variables and to understand how time influences their impact. The basic model including time dependent covariates is usually written as:

$$\log h_i(t) = \alpha(t) + \beta_1 x_{i,1}(t) + \ldots + \beta_k x_{i,k}(t)$$

The equation says that the hazard for individual i at time t is a function of a set of a baseline function at time t and k covariates at time t.

6.3.3 Dependent Variables

License Initiation (INV2LIC, pre-licensing phase)

Our data is an unbalanced, right censored panel. Each day a patented invention can be licensed or not and the license could be issued to a non-profit organization, an established firm, or a new firm. Therefore we track the date from invention disclosure to the date until one of the following events occurs: it is right censored or it is licensed out. The different forms of licenses that we consider in our analysis include exclusive and non exclusive licences and licensing options. Since the Cox regression needs a timing parameter that measures the time to event occurrence we count the number of days from the invention disclosure date to date of licensing the invention for each single invention disclosure. An observation that does not contain an event (e.g. licensing) is defined as a censored event and the time to event is counted as the number of days from the invention disclosure date to a fixed date. In our case we have chosen it to be the last date of observation to be 31/12/2003.

License Termination (LIC2LICTERM, post-licensing phase)

Since university inventions usually stem from basic research the inventions when licensed out to an industry partner need further investment to bring them to a commercially feasible state. Once an industry partner has licensed the invention he can reap the benefits but can also abandon and terminate the licence once it deems to be unprofitable. Therefore the unit of analysis in this survival analysis is the license itself. We track the termination of exclusive and non exclusive licenses and track the time to event from date of acquiring the license to the date the license is terminated. An observation that does not contain an event (e.g. termination) is defined as a censored event and the time to event is counted as the number of days from the date the license is acquired to a fixed fate (31/12/2003).

6.3.4 Independent Variables

Real option theory distinguishes between endogenous uncertainties (technological uncertainty) that are intrinsic to the firm and exogenous uncertainties (market uncertainty) which are dependent on the market and where the option holder has no influence upon. We will account for both types of uncertainties and explore how they affect the likelihood of invention commercialization and its timing.

Market uncertainty (INV2LIC, LIC2LICTERM)

The market uncertainty represents the randomness of the external environment and majority of research has measured randomness of demand to account for market uncertainty (e.g. Kulatilaka and Perotti, 1998) as demand impacts prices and therefore determines profitability (Folta and O'Brien, 2004). Since our study measures the uncertainty of the industry segment the patent is in, we will not consider macroeconomic uncertainty measures (e.g. GDP uncertainty) like the majority of real option literature but rather focus on micro-industry-specific uncertainty. Since our patents are representing 5 major technology fields which were classified by the TTO into Mechanical, Medical, Pharma & Biotech, Chemical and Electrical Technology, we will use these industry segments to calculate our market uncertainties.

The volatilities for each invention were calculated by computing the standard deviation of the industry clusters' daily stock returns. Since the invention disclosure dates were different across inventions we had to calculate market volatilities for each invention disclosure separately. The standard deviation of the stock market volatilities is specific to the industry subfield and exogenous to the control of individual firms and therefore represents a valid measure for market uncertainty.

It should be noted that stock index data that was used for the volatility calculations was not available for Germany. The available stock indices for Germany were either not dating back for the required time period or some technology industries was not available. Therefore, I have used the FTSE Eurotop300 Indexes that follow the stock prices of these 5 technology clusters for public European companies since 1987 and calculated the volatilities of the stock composite indexes using daily data obtained from DataStream. Since the majority of companies in these emerging technology industries are dependent on worldwide markets it is a valid assumption to use the European wide market uncertainty as it is mainly driven by macro industrial trends. For some industries where we could find a corresponding German stock index we have calculated correlations between the German and European Stock indices and found very high correlation coefficients (>95%) which further confirms our assumption.

The next question is how to estimate volatility from this data. A decision maker that has to make a investment decision which value is influenced by volatility (option like contracts) will have to evaluate how the volatility will behave in the future period t during his investment is active. If the investor has estimated (predicted) the volatility correctly over time period t his investment will realize this volatility and this volatility should be used to price an option like contract correctly. This is effectively the volatility that needs to be used in a real option theory framework.

An analogy with the financial markets in which a market to trade future volatility exists can be drawn in order to clarify this even further. The financial markets trade options that have different expiration dates. Each option is quoted a price in the market which is a consensus of multiple buyers and sellers. The market norm is usually to quote volatilities rather than prices because they are interchangeable and can be calculated one from the other. Therefore there is an agreement what the option is worth for a specific expiry (over a specific time period) and a volatility figure is determined by the market. This volatility is called implied market volatility for a specific expiry. This figure is what the whole market expects the option will realize until its expiration and would be the best measure of volatility.

Since historical option price data for specific industries does not exist the estimation has to be approached differently. There are two main approaches existing in current literature on real options handling this problem. Using a GARCH model and using historical volatility. In this research the historical volatility measure was chosen but the models were tested as well using the GARCH framework and it should be noted that it does not alter the model results in any way. A more detailed discussion on the robustness of the market uncertainty measure can be found in chapter 9.1.

Following standard formula was used to calculate the annualized volatility for each invention:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}\,\sqrt{252}$$

where σ is the annualized volatility, N the number of daily returns, xi the return in period i and $\bar{x}$ the average return over N periods.

As a reference date we have used the day when the invention was disclosed to the TTO for measuring the market uncertainty of the license initiation hypothesis. For the licensing termination hypothesis we measured the reference date when the license was contracted. We calculated for each invention the market uncertainty for 52 (similar to Folta 1998) prior to the invention disclosure date. Therefore for each patent we obtained a 1 year volatility window based on daily stock index return data. The reason for using the invention disclosure date rather than the date when the patent was granted as the reference date for our calculation is simply because some of the inventions can get commercialized even before the patent was granted.

Technological Uncertainty (INV2LIC, LIC2LICTERM)

We have previously defined technological uncertainty as the uncertainty regarding the technology development cost and the physical difficulty of completing the investment (Dixit and Pindyck, 1994). One possibility of measuring uncertainty is to ask experts such as technology transfer officers, inventors, and IP lawyers to assess the uncertainty of each technology patent individually at time of publication. Walker and Weber (1984) have utilized such an approach in measuring technological uncertainty in a two dimensional measure as “frequency of expected changes in specifications” and “probability of future technological improvements” measuring technology uncertainty of products for a small number of established firms. In our case this approach would be impracticable due to three reasons. Firstly, the large number of patents we consider in our analysis and the previous approach would limit the sample size drastically since the in depth analysis of a single patent can take several weeks and is very expensive (Markman et al., 2004). Secondly, we are considering uncertainty of already issued patents and it would not be efficient to ask professionals retrospectively about evaluations of patents that are already a couple of years old. Thirdly, technological uncertainty has dynamic characteristics as it fluctuates over time. To account for this problem, we would have to ask professionals if the technological uncertainty changed for each year after patent issuance, which makes this approach implausible. Therefore we will develop a measure which unravels all mentioned disadvantages and does not depend on primary measures.

Before a patent is issued, patent officers determine what previous patents and non patent literature must be cited in a patent by researching prior patents. Each of these citations refers to a specific date when the cited patent was issued. The citations show adjacent technological knowhow and with increasing average age of the citations, the technology field is more explored and more certain. Similar to Lowe (2002) we measure patent specific technological uncertainty (TU) for each patent as the average age of the cited patents (PC_j) and cited non patent literature (NPL_i), where j is the number of the cited patents and i is number of cited non patent literature entries. For the reference date to calculate the average age of patents we use the invention disclosure date for the licensing initiation hypothesis. For the licensing termination hypothesis the reference date for calculating the technological uncertainty is the date the license was contracted. This measure is valid as it provides the technological uncertainty at the time the invention was disclosed and is therefore not a retrospective measure of uncertainty. We define TU as:

$$TU = \frac{\frac{\sum_{j}^{m} PC_j}{m} + \frac{\sum_{i}^{n} NPL_i}{n}}{2}$$

Threat of Preemption

Similar to Geroski's (1995) argument that high industry concentration levels increase incumbent power to attack new entrants we argue that the higher the technological concentration in a technological field the higher the threat of preemption. Technological fields which are dominated by a smaller number of incumbents and therefore are more concentrated will be more likely involved in preemptive strategies to protect their technologies, which will lead to higher threat of preemption.

Similar to the Herfindahl index, that measures industry concentration by summing squared market shares of leading companies in an industry, we will measure technological concentration and therefore threat of preemption as sum of squared patent shares of rivals in the same technological domain (patent subclass) during year t. Rivals are defined as any other organization (for-profit or not-for profit such as other universities) issuing patents in the same patent subclass. We define patents in the same technology areas when their international patent classification code equate.

TC_{it} is the patent concentration of rivals in patent subclass *i* in year *t* indicated by the sum of patent shares PS_{ikt} for companies *k*=1 to *n*. We define patent share (PS_{ikt}) as the number of patents (P_{ikt}) in a subclass *i* company *k* has issued in a given year *t* divided by the total number of patents (TP_{it}) issued in this sub-class i.

$$TC_{it} = \sum_{k=1}^{n} PS_{ikt}^{\ 2}$$

$$PS_{ikt} = \frac{P_{ikt}}{TP_{it}}$$

6.3.5 Control Variables

Invention Experience (INV2LIC, LIC2LICTERM)

Currently the Max Planck Society maintains 80 institutes, research units, and working groups that are devoted to a wide range of research areas. The institutes are organized in a way that each institute specializes in a certain technology field. The institutes work largely in an interdisciplinary setting and in close cooperation with universities and other research institutes in Germany and abroad to generate cutting-edge knowledge and technological breakthroughs in diverse technological areas. The institutes themselves produce difference amount of inventing output which can affect the amount of licenses generated as well as terminated. Therefore we control for the number of inventions each institute has disclosed to the TTO before the current invention was disclosed as a measure of inventive experience.

Licensee Experience (INV2LIC, LIC2LICTERM)

Similar to Ziedonis (2007) we measure the number of previous licenses a licensee has acquired from MPS. Firms that have previously licensing experience with a MPS invention may be better able to evaluate a new technology in related areas. Our measure for previous licensing experience with MPS equals 1 if the firm has previously licensed a patent from an MPS and equals 0 otherwise.

Technical field (INV2LIC, LIC2LICTERM)

A cross industry variation of licensing behaviour was observed by Anand and Khanna (2000). We will therefore control for the technology fields the patents are in, since certain technology fields that the different research institute cover are more likely to be commercialized than others. Similar to Shane (2001b) we will include dummy variables for mechanical, electrical, chemical and biopharmaceutical inventions.

Time controls (INV2LIC, LIC2LICTERM)

We control for effects of time by using a time dummy variable for the period between 1995 and 2003. The reason for the time control is the fact that Max Planck has proactively changed its policy towards commercializing their IP from this time period. Therefore we expect the highest number of licensing agreements after 1995.

Partnered Research (INV2LIC, LIC2LICTERM)

Inventions that are resulting from partnered research, especially partnered with industry, can be more commercially oriented. Further partnering with other universities and public research organizations can result in a more effective knowledge transfer. This can have effect on both the licensing probability as well as termination. We therefore control for partnered research if the invention was partnered with an industry partner, with another public research organization or a university.

Funded Research (INV2LIC, LIC2LICTERM)

Funding does suggest a particular interest in the research underlying the patented invention. We therefore control for funding that equals 1 if the invention that has led to the patent under consideration was funded and equals 0 otherwise.

Age of technology class (INV2LIC, LIC2LICTERM)

New technologies are more likely to be commercialized when the field of technology is young. We will therefore measure the age of technology class as the number of days between the IPC (international patent class) code was first issued by the patent office and the patent publication date. The difference between age of technology class and technological uncertainty should be elaborated at this point. The age of technology class measures how old the technology class is which is not necessarily related to technological uncertainty. One can assume that an older technology class is also less uncertain but it is still common to observe technological breakthroughs in old technology classes. This is exactly what the technology uncertainty variable tries to capture by analysing the average age of citations rather than the age of technology class. Table 1 shows that the correlations of these two variables are relatively low which strengthens the argument that there is little association between the two variables.

Patent scope (INV2LIC, LIC2LICTERM)

To control for the patent scope we include Lerner's (1994) measure of patent scope, which is based upon the number of technological classes the patent is categorized into. Patents that are classified into more technological areas are broader in scope according to Lerner (1994) and Shane (2001b) and are more valuable. According to Lerner this measure captures different dimensions of economic importance e.g. firm valuation, likelihood of patent litigation and citations. Therefore it should increase the likelihood of licensing an invention and decrease the likelihood of termination.

Patent Quality (INV2LIC, LIC2LICTERM)

Previous research has argued that a measure for patent quality can be derived from the fact how many other patents the claims and to how many other patents and non patent literature the patent refers to (Lerner, 1994). We control for patent claims and references since patent value should increase the likelihood of licensing and decrease licensing termination.

Start Up (INV2LIC, LIC2LICTERM)

We control if the licensee is a start-up company. In each year a patent could be licensed or not and the license could be issued to an established firm, or a new firm. Similar to Shane (2001b) we define firm formation as occurring in a given year, if the invention was licensed to a for-profit firm that did not exist as a legal entity in the previous year. As we have shown in the previous chapter the characteristics of the licensee can influence how the market and technological uncertainty affects licensing or spinning out and termination or firm failure.

Previous Technology Transfer Experience (INV2LIC)

We measure the previous technology transfer experience of a technology transfer officer as the amount of previous inventions they have disclosed and have supported before a certain invention was disclosed. A highly experienced technology transfer officer may be more successful at licensing out inventions which we account for with this control variable.

6.4 Results

6.4.1 Prelicensing Phase (INV2LIC)

Table 6-1 reports the descriptive statistics and Table 6-2 bivariate correlations for the independent variables in the initial regression analysis respectively. The total amount of inventions considered is 1123 which result in 484 events (licenses contracted).

Table 6-1: Descriptive Statistics (INV2LIC)

Variables	N	Min	Max	Mean	Std. Dev.
Mechanical	1123	0.00	1.00	0.06	0.24
Chemical	1123	0.00	1.00	0.27	0.44
Pharma & Bio	1123	0.00	1.00	0.44	0.50
Medical	1123	0.00	1.00	0.10	0.30
Year Issued (1995-2003)	1123	0.00	1.00	0.48	0.50
Patent References	1123	0.00	29.00	5.21	3.93
Patent Quality	1123	0.00	613.00	18.48	25.32
Patent Scope	1123	0.00	19.00	2.63	2.77
Technology Age	1123	0.00	77.33	15.96	13.06
Funded Research	1123	0.00	1.00	0.09	0.28
Partnered Research	1123	0.00	1.00	0.37	0.48
Invention Experience	1123	0.00	212.00	39.11	42.82
Licensee Experience	1123	0.00	228.00	25.97	35.15
Previous Technology Transfer Experience	1123	0.00	144.00	31.73	31.59
Market Uncertainty	1123	0.09	0.49	0.21	0.07
Technological Uncertainty	1123	-9.13	0.00	-1.15	1.28
Threat of Preemption	1123	0.77	6.12	2.62	0.76

We provide six models for the pre as well as the postlicensing phase in our analysis. The main model for the prelicensing phase can be found in Table 6-3 and the different model steps can be found in the Appendix. Model 1 in presents the base model for the prelicensing phase and predicts the likelihood of licensing on the basis of industry and time controls. Overall the model is significant (chi-square = 31.2, $p < 0.001$). As Model 1 shows, licensing out an invention was the lowest for chemical patents ($b = 0.67$, $p < 0.001$) among other industrial controls with the highest being medical ($b = 0.92$, $p < 0.001$). It should be noted that the reference industry is the electrical industry, which was omitted from the industry controls to prevent falling into the dummy variable trap, which implies perfect collinearity between the dummy variables (Gujarati, 2008). Further biopharmaceutical patents are 0.85 ($p < 0.001$) times more likely to be licensed out.

The correlation table (Table 6-2) shows that the correlation coefficient of the independent variables does not exceed $r = 0.54$. The only exception is between *invention experience* and *licensee experience* where the correlation coefficient is $r = 0.86$ which is relatively high and multicollinearity can become a problem. We have performed analyses including and excluding these two variables and the results were stable concluding that multicollinearity is not a concern in this analysis.

Table 6-2: Correlation Matrix (INV2LIC)

	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1.	Mechanical	1.00																
2.	Chemical	-0.15	1.00															
3.	Pharma & Bio	-0.22	-0.54	1.00														
4.	Medical	-0.08	-0.20	-0.29	1.00													
5.	Year Issued (1995-2003)	0.02	-0.10	0.08	-0.02	1.00												
6.	Patent References	-0.10	-0.08	0.16	0.04	0.13	1.00											
7.	Patent Quality	-0.02	0.04	0.04	-0.05	0.07	0.13	1.00										
8.	Patent Scope	-0.13	-0.03	0.20	0.01	-0.07	0.18	0.16	1.00									
9.	Technology Age	0.14	0.16	-0.28	0.01	-0.04	-0.08	0.00	-0.07	1.00								
10.	Funded Research	-0.01	-0.05	0.08	-0.03	0.19	0.01	0.02	-0.03	-0.05	1.00							
11.	Partnered Research	-0.06	0.08	0.03	0.06	0.08	0.10	0.08	0.12	-0.04	0.12	1.00						
12.	Invention Experience	-0.03	0.10	0.02	-0.03	0.05	0.06	0.09	-0.09	0.02	0.12	0.08	1.00					
13.	Licensee Experience	-0.05	0.01	0.12	-0.02	0.10	0.11	0.06	-0.03	-0.02	0.11	0.09	0.86	1.00				
14.	Previous Technology Transfer Experience	-0.04	0.08	-0.04	0.02	0.17	0.04	0.13	-0.09	0.07	0.03	0.07	0.40	0.32	1.00			
15.	Market Uncertainty	0.01	-0.19	-0.08	0.21	-0.03	-0.01	0.03	-0.10	0.14	0.09	-0.01	0.27	0.22	0.19	1.00		
16.	Technological Uncertainty	-0.04	-0.11	0.16	0.02	-0.01	-0.23	0.01	0.07	-0.16	0.01	0.02	-0.02	0.01	-0.06	-0.06	1.00	
17.	Threat of Preemption	0.18	0.15	-0.44	0.00	-0.03	-0.14	-0.02	-0.14	0.25	0.01	-0.04	0.01	-0.08	0.03	0.19	-0.07	1.00

Model 2 reports the baseline model with nine additional controls. The inclusion of these control variables provides a good fitting model (chi-square = 214, $p < 0.001$) and the three significant variables are *previous licensee experience* ($b = 0.007$, $p < 0.05$, *partnered research* ($b = 0.999$, $p < 0.001$) and *patent references* ($b = 0.023$, $p < 0.1$).

Table 6-3: Cox Regression Analysis for the determinants of licensing (INV2LIC)

Variables	Model 1	Model 2	Model 3
Mechanical	-0.055	-0.153	-0.279
Chemical	0.668 ***	0.292	0.191
Pharma & Bio	0.849 ***	0.437 *	0.147
Medical	0.924 ***	0.533 *	0.239
Patent References		0.023 †	0.025 *
Patent Quality		0.002	0.002
Patent Scope		-0.006	-0.005
Technology Age		-0.005	-0.005
Funded Research		0.031	-0.017
Partnered Research		0.999 ***	0.998 ***
Invention Experience		0.399	0.203
Licensee Experience		0.007 **	0.006 *
Tech. Trans. Experience		0.002	0.001
Market Uncertainty			12.36 *
Market Uncertainty Square			-27.94 *
Technological Uncertainty			0.054
Threat of Preemption			-0.195 *
N	1123	1123	1123
Model X^2	31.2 ***	214 ***	225 ***
-2 Log Likelihood	4931 ***	4776 ***	4762 ***

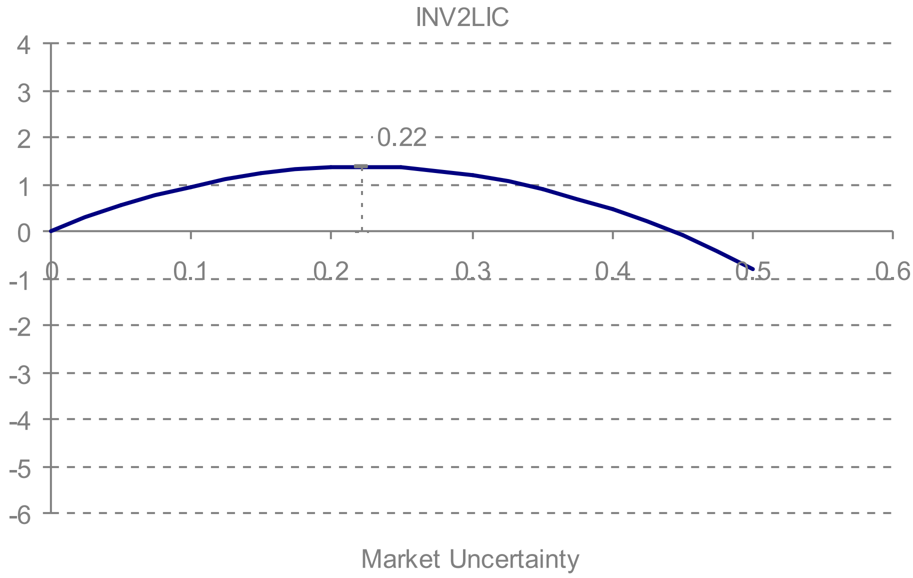
Note: The dataset includes 1123 cases and 383 events and two-tailed tests for all variables

† $p < 0.1$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

Technology age had a negative impact on the likelihood of contracting a license (although not statistically significant) which shows the fact that newer technologies are more likely to be commercialized. Cutting edge research and new technologies is the area where PRO's and university contribute most to knowledge creation and industrial licensees are more likely to contract inventions in these areas. *Licensee experience* had a significant positive relationship with licensing. This result indicates that previous licensee experience influences the licensing and commercialization likelihood of research. It seems that licensees that have a strong working relationship with the PRO are better able to evaluate technologies and mitigate uncertainty found in inventions leading to a higher licensing rate. It seems that potential licensees are more aware and less careful when evaluating an invention if they have previous experience in commercializing research from PRO's. As expected the experience of the technology transfer officer increases the likelihood of licensing out inventions. A strong predictor of licensing is *partnered research* which has a positive relationship with licensing. Industry partners usually collaborate with PRO's on inventions where they have already evaluated commercial potential and therefore are more likely to license it after successful development. These findings that links basic research and research output quantity with commercial value might provide an insight on the debate to what extent university research should be commercialized.

Model 3 includes technological uncertainty, market uncertainty and threat of preemption as predictor variables and shows that inclusion of the variables generates a good fitting model (chi-square = 225, $p < 0.001$). These results generally support hypotheses 1 and 3 whereas Hypothesis 2 is not supported. Hypothesis 1 is confirmed by Model 3 which shows that market uncertainty has a nonmonotonic effect on the likelihood of selling the option in form of a license. Inconsistent with hypothesis 2, the excessive technological uncertainty does not significantly increase the likelihood of licensing. Hypothesis 3 is confirmed with threat of preemption negatively influencing likelihood of licensing ($b = -0.20$, $p < 0.05$).

Figure 6-1 Effects of Market Uncertainty on Licensing



6.4.2 Postlicensing Phase (LIC2LICTERM)

The descriptive statistics and bivariate correlations are reported in Table 6-5 and Table 6-5 respectively. The licensing universe consists of 484 licenses and 146 license terminations.

Table 6-4: Descriptive Statistics (LIC2LICTERM)

Variables	N	Min	Max	Mean	Std. Dev.
Mechanical	484	0.00	1.00	0.03	0.16
Chemical	484	0.00	1.00	0.24	0.43
Pharma & Bio	484	0.00	1.00	0.55	0.50
Medical	484	0.00	1.00	0.11	0.32
Year Issued (1995-2003)	484	0.00	1.00	0.58	0.49
Patent References	484	0.00	29.00	5.93	4.18
Patent Quality	484	0.00	613.00	20.25	34.90
Patent Scope	484	0.00	19.00	3.12	3.01
Technology Age	484	0.00	72.97	13.29	12.42
Funded Research	484	0.00	1.00	0.09	0.28
Partnered Research	484	0.00	1.00	0.58	0.49
Invention Experience	484	0.00	202.00	40.74	41.32
Licensee Experience	484	0.00	146.00	31.08	32.70
Previous Technology Transfer Experience	484	0.00	136.00	32.89	31.64
Market Uncertainty	484	0.07	0.38	0.16	0.05
Technological Uncertainty	484	-7.59	0.00	-1.87	1.42

Table 6-5: Correlation Matrix (LIC2LICTERM)

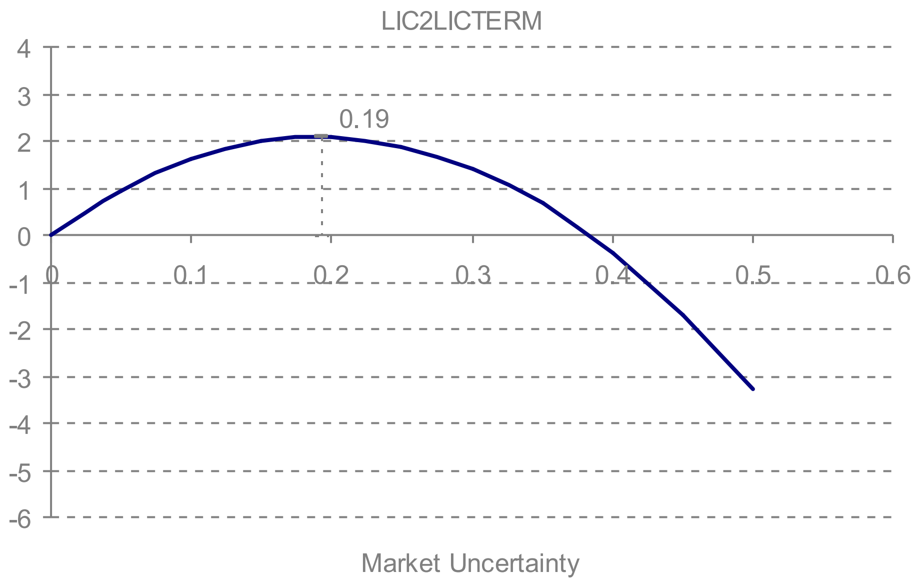
	Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1.	Mechanical	1.00															
2.	Chemical	-0.09	1.00														
3.	Pharma & Bio	-0.18	-0.61	1.00													
4.	Medical	-0.06	-0.20	-0.39	1.00												
5.	Year Issued (1995-2003)	0.04	-0.07	0.02	-0.01	1.00											
6.	Patent References	-0.07	-0.06	0.06	0.09	0.02	1.00										
7.	Patent Quality	-0.04	0.01	0.01	-0.01	0.08	0.14	1.00									
8.	Patent Scope	-0.09	-0.08	0.18	0.00	-0.10	0.22	0.19	1.00								
9.	Technology Age	0.05	0.12	-0.29	0.17	-0.09	-0.02	-0.01	0.00	1.00							
10.	Funded Research	-0.05	-0.03	0.09	-0.09	0.20	0.03	-0.02	-0.07	-0.08	1.00						
11.	Partnered Research	0.04	0.14	-0.10	0.00	-0.04	0.03	0.05	-0.01	0.07	0.17	1.00					
12.	Previous Inventions	0.02	0.19	-0.07	-0.01	0.10	0.06	0.02	-0.05	-0.06	0.10	0.09	1.00				
13.	Previous Licensee	-0.05	0.12	0.02	-0.03	0.10	0.12	-0.02	0.02	-0.09	0.09	0.03	0.93	1.00			
14.	Previous Technology Transfer Experience	-0.03	0.07	-0.10	0.07	0.23	0.06	0.11	-0.07	0.04	0.02	0.04	0.50	0.43	1.00		
15.	Market Uncertainty	-0.05	-0.17	-0.13	0.09	0.35	-0.03	0.01	-0.09	0.09	0.05	-0.09	0.04	0.02	0.17	1.00	
16	Technological Uncertainty	0.00	-0.11	0.08	0.03	0.05	-0.33	0.02	0.00	-0.06	0.08	-0.01	0.07	0.04	0.12	-0.10	1.00

Similar to the prelicensing phase in the previous chapter, Model 1 presents the base model for the postlicensing phase and predicts the likelihood of termination. It includes the industry and time controlling variables and only the time control is positively significant to the likelihood of terminating of a licensing agreement.

Model 2 includes reports the baseline model with nine additional controls. The inclusion of these control variables provides a good fitting model (chi-square = 107, $p < 0.001$) and the significant variables are *funded research* ($b = 0.84$, $p < 0.05$) *partnered research* ($b = -1.6$, $p < 0.001$), *invention experience* ($b = 0.018$, $p < 0.05$) and *licensing experience* ($b = -0.014$, $p < 0.1$). Partnering with another institution (industry, PRO or university) seems to be a very good predictor as expected and has a negative influence on terminating a license. Institutions that partner with the inventors are clearer about the technology development process as well as the commercialization potential making them less likely to terminate a licensing contract. Further licensing experience has a negative but not highly significant effect on license termination. An interesting finding is that *invention experience* has a positive and significant effect on licensing termination. If it is considered that licensing termination indicated that the value of the invention does not fulfil expectations this shows that pure research output (measured by *invention experience*) by an institution does not guarantee quality of research output. As was shown earlier, previous technology transfer officer experience is positively correlated to license initiation. The same effect can be observed for license termination leading to a question whether experienced technology transfer officers are good at selling licenses that do not prove to be of great commercial value in the market.

Both of these findings link basic research and research output quantity with commercial value and might provide an insight on the debate to what extent university research should be commercialized.

Figure 6-2 Effects of Market Uncertainty on Licensing Termination



Model 3 includes technological uncertainty and market uncertainty and their squares as predictor variables and presents a good fitting model (chi-square = 119, $p < 0.001$). These results generally support hypotheses 4 and 5. Hypothesis 4 is confirmed by Model 3 which shows a significant nonmonotonic relationship with license termination where increasing market uncertainty positively influences licensing termination until a saturation point at which market uncertainty negatively influences it. Further as proposed by hypothesis 5, excessive technological uncertainty increases the likelihood license termination ($b = 0.15$, $p < 0.05$).

Table 6-6: Cox Regression Analysis for the determinants of licensing termination (LIC2LICTERM)

Variables	Model 1	Model 2	Model 3
Mechanical	-0.583	-0.314	-0.236
Chemical	-0.494	-0.120	0.201
Pharma & Bio	-0.115	0.001	0.103
Medical	-0.197	0.065	-0.057
Year Issued (1995-2003)	0.894 ***	1.045 ***	1.229 ***
Patent References		0.015	0.034
Patent Quality		-0.007	-0.009 †
Patent Scope		-0.039	-0.064 †
Technology Age		-0.004	-0.005
Funded Research		0.838 *	0.724 *
Partnered Research		-1.632 ***	-1.703 ***
Previous Inventions		0.018 *	0.020 **
Previous Licensee		-0.014 †	-0.018 *
Previous TT Experience		-0.000	-0.001
Market Uncertainty			21.71 **
Market Uncertainty Square			-56.57 *
Technological Uncertainty			0.150 *
N	484	484	484
Model	22.6 ***	107 ***	119 ***
-2 Log Likelihood	1540 ***	1451 ***	1433 ***

Note: The dataset includes 484 cases and 146 events and two-tailed tests for all variables

† $p < 0.1$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

6.5 Discussion and Conclusion

In this chapter we analyse data on the population of Max Planck inventions over the 1990 – 2003 period and found that market as well as technological uncertainty influences the likelihood that an invention will be licensed in the pre-licensing phase and abandoned/ terminated in the post licensing phase. We therefore present evidence that inventions have option like characteristics in different phases of their lifecycle. The empirical results provide strong support for the view that the uncertainty regime the invention and license is found in is important for understanding the technology lifecycle.

In more detail we found that in the pre-licensing phase market uncertainty has a positive effect on licensing whereas threat of preemption has a negative effect. Unlike suggested in Hypothesis 2 technological uncertainty does not have a significant negative relationship to licensing. In the post licensing phase we found that both postulated hypotheses are significant, namely that high market uncertainty has a negative impact on licensing termination whereas technological uncertainty is positively influencing it.

Our methodological design resembles the design of Shane (2001b) and assures the validity of the results due to following characteristics. In the analysis of the pre-licensing phase as well as the post-licensing phase our design includes the complete population of patents and licenses issued and therefore avoids sample selection bias within the dataset.

Contributions to two streams of research are addressed, namely the innovation and licensing literature as well as the real option literature. Previous empirical studies on technology licensing (e.g. Anand and Khanna, 2000) have analyzed licensing events and the license contract structures and are generally extremely rare in nature due to the difficult accessibility of data which makes contributes to the fact that understanding of licensing is significantly further behind empirical understanding of other issues in contracting (Anand and Khanna, 2000). Existing studies are generally able to examine factors that influence the decision on an aggregated level rather than on the invention level. Our study overcomes this limitation by utilizing this specific dataset as well as studying different lifecycles of the innovation.

We are therefore the first to examine empirically different forms of uncertainty in the lifecycle of an invention and its effects on the licensing likelihood and licensing termination likelihood. Our results show significant but opposing effects of endogenous and exogenous uncertainty when an invention is licensed and when it is terminated/ abandoned. We demonstrate that commercialization and termination of agreements changes with uncertain market conditions as well as with the uncertainty regime the technological opportunity is found in. The dynamic nature of market uncertainty will affect the amount of licenses contracted out.

The results of this study also suggest that option value can be firm specific e.g. firms that have a higher licensing experience are more likely to license an invention. These firms are more familiar with the process of licensing and technology transfer and more likely to be better able to evaluate external technologies. This supports findings by Arora and Gambardella (1994) that their internal knowledge base allows firms to be more confident about their decision making in uncertain environments and benefiting from their ‘absorptive capacity’.

Recently real option studies have analyzed and tried to explain a wide range of phenomena especially in the range of strategic decisions (Amram and Kulatilaka, 1999). Still very little empirical work has tested the predictions made by real option theory on the value and optimal decision timing of option contracts Ziedonis (2007). Our objective in this paper was therefore to understand how managers use real options in the different phases of its lifecycle. Empirical justification of real option theory represents an important contribution to the literature as it gives evidence for the applicability of real option reasoning for a wide range of phenomena.

6.5.1 Interaction Effects

The tests for the interaction effects for all dependent variables can be found in chapter 9.4.6 for the licensing model whereas the chapter 9.4.8 contains the analysis for the interaction effects of licensing failure.

The licensing model shows several statistically significant interaction effects which are summarized in Table 6-7.

Table 6-7 Summary of interaction effects for the licensing model

Interactions	**Coefficient**
Market Uncertainty * Patent Quality	-0.598 **
Market Uncertainty Square * Patent Quality	1.879 **
Technological Uncertainty * Partnered Research	-0.313 *
Technological Uncertainty * Invention Experience	-1.858 †

Threat of Preemption * Technology Age	0.16 *
Threat of Preemption * Partnered Research	0.656 ***
Threat of Preemption * Invention Experience	0.003 †
Threat of Preemption * Licensing Experience	0.004 *

† $p < 0.1$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

- In more certain markets patent quality attenuates the effect of market uncertainty on licensing an invention whereas in uncertain markets patent quality accentuates the effects of market uncertainty on licensing
- Technologies that are more certain are more likely to be licensed when they were developed in partnered research efforts whereas when technologies are uncertain they more likely to be licensed when they were not developed in partnered research efforts
- Technologies that are more certain are more likely to be licensed when the invention experience is high whereas when technologies are uncertain they more likely to be licensed when invention experience is low
- When threat of preemption is high, inventions whose technology age is high are more likely to be licensed whereas when threat of preemption is low, inventions are more likely to be licensed when their technology age is low
- When threat of preemption is high inventions that were developed in partnered research efforts are more likely to be licensed whereas when

threat of preemption is low inventions are more likely to be licensed when their development was not developed in partnered research efforts

- When threat of preemption is high inventions are more likely to be licensed that were developed by highly experienced inventors whereas when threat of preemption is low inventions are more likely to be licensed when they are developed by inventors with less experience
- When threat of preemption is high inventions are more likely to be licensed to licensees with high licensing experience whereas when threat of preemption is low inventions are more likely to be licensed to licensees with low licensing experience

The interaction effect model for licensing failure only has interaction effects with technology transfer experience and technology age which can be seen in Table 6-8.

Table 6-8 Summary of interaction effects for the licensing failure model

Interactions	**Coefficient**
Market Uncertainty * Patent Quality	-0.59 *
Market Uncertainty Square * Patent Quality	1.49 *
Technological Uncertainty * TTO Experience	-0.01 **
Technological Uncertainty * Technology Age	-0.01 †

† $p < 0.1$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

- In more certain markets patent quality attenuates the effect of market uncertainty on licensing termination whereas in uncertain markets patent quality accentuates the effects of market uncertainty on licensing termination

- Technologies that are more certain are more likely to be terminated when the technology transfer officer experience is high whereas when technologies are uncertain they more likely to be terminated when technology transfer experience is low
- Technologies that are more certain are more likely to be terminated when the technology age is high whereas when technologies are uncertain they more likely to be terminated when technology age low

6.6 Competing Risk Model

Competing risk models enable the comparison of survival models with mutually exclusive outcomes for the dependent variables. The model starts for one observation at the same point in time and is observed until the first duration of the first dependent variable occurs first. The most common models in econometrics where competing risk models are used are the study of e.g. individual unemployment durations. The individual in unemployment is observed until either transition into employment occurs or into non participation. Other applications include the modelling of the duration of marriage where one risk is the divorce and the other the death of one of the spouses.

In our analysis one competing risk model is of particular interest, namely the comparison between spinout and licensing. As we draw the data from the same pool of inventions it would be interesting to understand if there are fundamental differences between these two competing risks and how the effect of independent variables differs between the two risk modes.

Although we have postulated and proven in our previous hypotheses that market uncertainty affects spinout and licensing differently we are including market uncertainty into the competing risk model for the reason of completeness of the model.

The results for the overall significance can be found in Table 6-9. In order to compare the overall significances it is first required to estimate the log likelihoods of the individual models and compare each individual model to the joint occurrence of both events. Therefore I have constructed a third model that takes into account combined occurrences i.e. licensing and spinout and estimated it and compared it against the individual risk modes. Table 6-9 shows that the overall difference between the two modes of spinout formation and licensing is highly statistically significant with a log likelihood of 76.6 and $p<0.001$ which confirms the overall assumption that licensing an invention and creating a spin-out is different compared to licensing an invention to an established company.

Table 6-9 Overall Significance for Competing Risk Model for Spin-out formation vs. Licensing model

Dependent Variables	**-2 Log Likelihood**	**Degrees of Freedom**
Spinout and License	5981.745396	20
License	4742.959233	20
Spinout	1162.184141	20
Difference	76.60 ***	20

† $p < 0.1$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

Table 6-10 shows the competing risk model for each individual variable and shows where the relationships differ significantly on individual covariate level. Looking at the industry dummies it can be seen that only the medical industry dummy is significantly different between spinouts and licenses. Although medical inventions have a positive relationship in both licensing and spinning out models, they have a stronger statistically significant influence on firm formation then on licensing. This leads to the conclusion that medical inventions are around 10 times more likely to be exploited via a spinout then a license.

It was shown in previous analyses that on the individual model level the likelihood of licensing or spinning out is affected differently across industries. The competing risk model shows on the other hand that across the competing risks there is no statistically significant difference except for the previously mentioned medical industry. This is somewhat surprising as one would expect e.g. less capital intensive industries to prefer spinning out whereas licensing to occur in more concentrated industries.

Table 6-10 Competing Risk Model for Spinout formation vs. Licensing model

Variables	License (b1)	License (StdErr)	Spinout (b1)	Spinout (StdErr)	Chi Square	P
Mechanical	-0.403	0.366	1.418	1.100	2.47	0.116
Chemical	0.533	0.427	1.103	1.207	0.20	0.656
Pharma & Bio	0.001	0.536	1.327	1.349	0.83	0.361
Medical	0.294 *	0.403	3.016	1.143	5.04	0.025
Year Issued (1995-2000)	0.279	0.123	0.509	0.233	0.76	0.383
Patent References	0.023	0.013	-0.029	0.031	2.43	0.119
Patent Quality	0.002	0.002	0.005	0.003	0.70	0.403
Patent Scope	0.002	0.018	-0.004	0.036	0.03	0.874
Technology Age	-0.005 *	0.005	-0.032	0.010	5.92	0.015
Funded Research	-0.089	0.193	0.163	0.287	0.53	0.467
Partnered Research	0.994	0.109	0.838	0.220	0.40	0.526
Invention Experience	0.597	2.653	-6.080	5.064	1.36	0.243
Licensee Experience	0.007	0.003	0.012	0.006	0.73	0.393
Technology Transfer Experience	0.001 *	0.002	0.01	0.003	4.54	0.033
Firm Size	0.003	0.003	0.009	0.006	1.06	0.302
R&D Intensity	-0.165	0.050	-0.203	0.133	0.07	0.790
Market Uncertainty	11.137 ***	5.026	-21.037	8.608	10.42	0.001
Market Uncertainty Square	-26.298 ***	13.223	54.681	18.017	13.13	0.000
Technological Uncertainty	0.059 *	0.049	0.401	0.153	4.54	0.033
Threat of Preemption	-0.201	0.088	-0.013	0.191	0.79	0.373

Out of the other covariates only three statistically significant differences are observed:

- Technology Age ($p<0.05$)
- Technology Transfer Experience ($p<0.05$)
- Market Uncertainty ($p<0.001$)
- Market Uncertainty Square ($p<0.001$)
- Technological Uncertainty ($p<0.05$)

Higher technology age decreases the likelihood that an invention will lead to a spinout or be licensed out but the effect of technology age on spinning out is stronger than on licensing ($b_{license}$ = -0.005 vs. $b_{spinout}$ = -0.03) showing that the effect of technology age is 6 times stronger for spinning out an invention. This finding shows that inventions that are spun out are much more sensitive to the technology age then to the route of licensing. This finding extends Shane's (2001a) that younger and more radical technologies are leading to spinouts. In his work Shane has only looked at the effects of technology age and radicalness of technologies regarding spinning out. This finding builds on his work and extends it in such a way that the effect of technology age is much stronger for spinning out inventions then on competing risks such as licensing.

Technology transfer experience has a similar effect on licensing and spinning out in that it is a much stronger predictor on spinouts then on licenses ($b_{license}$ = 0.001 vs. $b_{spinout}$ = 0.01). Inventions that are commercialized through a much more experienced technology transfer officer are much more likely to be spun out then licensed. Spinning out an invention rather than licensing is a much more complex process from the technology transfer officer point of view and require them to supervise the inventors through a completely different i.e. more complex process. This finding can be understood that more experienced technology transfer officers are more familiar with the complexity of the spinout process and are more comfortable advising the founders in this direction. What needs to be established is the answer comparing quantity vs. quality. Are the larger amount of spinouts supervised by experienced technology transfer officers as good performing as the other spinouts or even better? The answer to this question could be an avenue for further research.

The entry decision is characterised by a tension between the option to defer and the option to grow which was discussed by Folta and O'Brien (2004): "The option to defer obtains its value from the potential for a manager to defer the entry decision, which allows a firm to 'keep its options open' and avoid the opportunity costs associated with making an irreversible investment (McDonald and Siegel, 1986). Factors that increase the value of the option to defer, such as greater sunk costs associated with the investment, make entry less likely. Alternatively, the option to grow gains its value from the possibility that early investment will help the firm to develop a 'capability' that will allow it to take better advantage of future growth opportunities in the industry (Kulatilaka and Perotti, 1998). Accordingly, more valuable growth options encourage investment and make entry more likely."

In this dissertation, entry was analysed for both the spinout decision and licensing decision and in both decisions the tensions between growth options and options to defer were discussed. Due to the presence of both options and the tension between these arising, the effect of uncertainty is non monotonic on entry for the two competing risks of commercialising an invention.

The different effects of uncertainty on entry of these competing risks can be explained due to the different exposures to growth and deferment options.

The decision maker who is planning to exploit an invention via the spinout route is fully exposed to the effects of both growth and deferments options. On the other hand when licensing the invention the decision maker has limited upside potential since the licensee captures it but there is as well very little downside risk. An alternative interpretation is that spinouts represent the purchase of a call option whereas licensing represents the sale of a call option.

Figure 6-3 Effects of Market Uncertainty on Spinout formation and Licensing

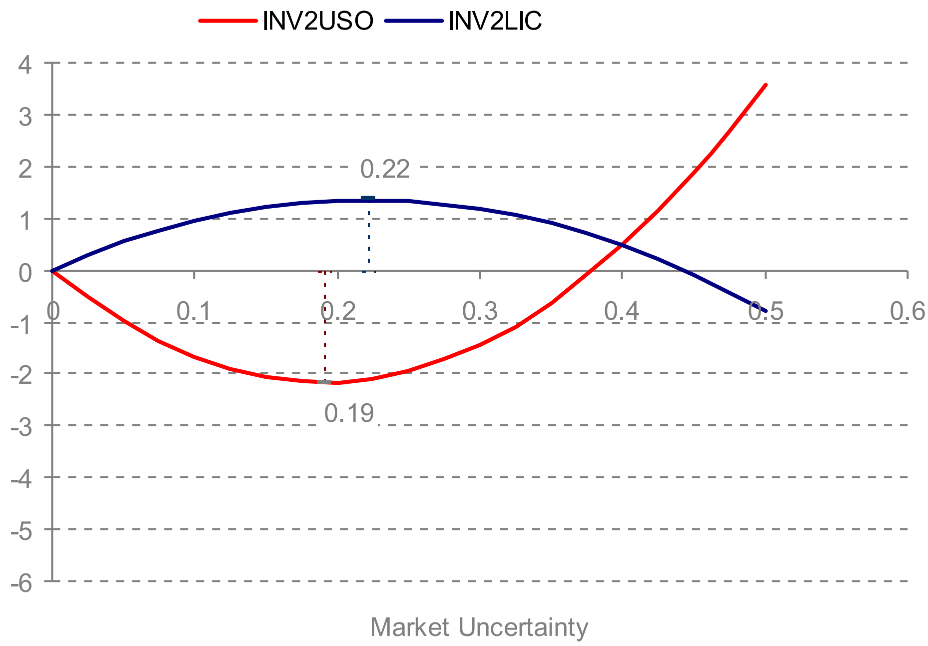


Figure 6-3 shows the effects of market uncertainty on the likelihood of firm formation and the likelihood of licensing. It is evident that the effects of market uncertainty on both spinout formation and licensing are non monotonic but with opposite signs. The red line shows a U-shaped curve suggesting that the option to defer dominates at the lowest levels of market uncertainty (note the initially downward sloping line), but the option to grow dominates at higher levels of uncertainty. This implies that high market uncertainty inspires the technology holder to spinout in order to take advantage of the potentially high upside potential.

The blue line on the other hand represents the influence of market uncertainty on licensing. It is inverted to the spinout formation curve but its convexity is around two times smaller[8]. This is expected since licensing an invention would expose the decision maker to either the option to defer or the option to grow much less compared to spinning out the invention.

The inversion of the blue line shows that at low levels of market uncertainty, market uncertainty has a positive effect on licensing whereas at high levels of uncertainty market uncertainty has a negative effect on licensing. As can be seen an increased preference for licensing can be observed for market uncertainties up until 22.5%. The reason is that because licensing provides a guaranteed income (licensing fee and royalties) it is preferred as uncertainty gets higher. However, at some high level of uncertainty the costs of developing the technol-

[8] Equations used in the calculation of the influence of market uncertainty on spinout formation and licensing:

$INV2USO(\sigma) = -22.8\sigma + 59.9\sigma^2$

$INV2LIC(\sigma) = 12.3\sigma - 27.9\sigma^2$

$$\left|\frac{\partial^2 INV2USO}{\partial^2 \sigma}\right| = 116.6 > \left|\frac{\partial^2 INV2LIC}{\partial^2 \sigma}\right| = 55.8$$

ogy overwhelm the likelihood of extracting any license so it does not occur and it requires a different mode of commercialization i.e. the spinout route.

The last statistically significant effect in the competing risk model is technological uncertainty which is more than 6 times stronger for spinouts then for licensing ($b_{license} = 0.06$ vs. $b_{spinout} = 0.4$).

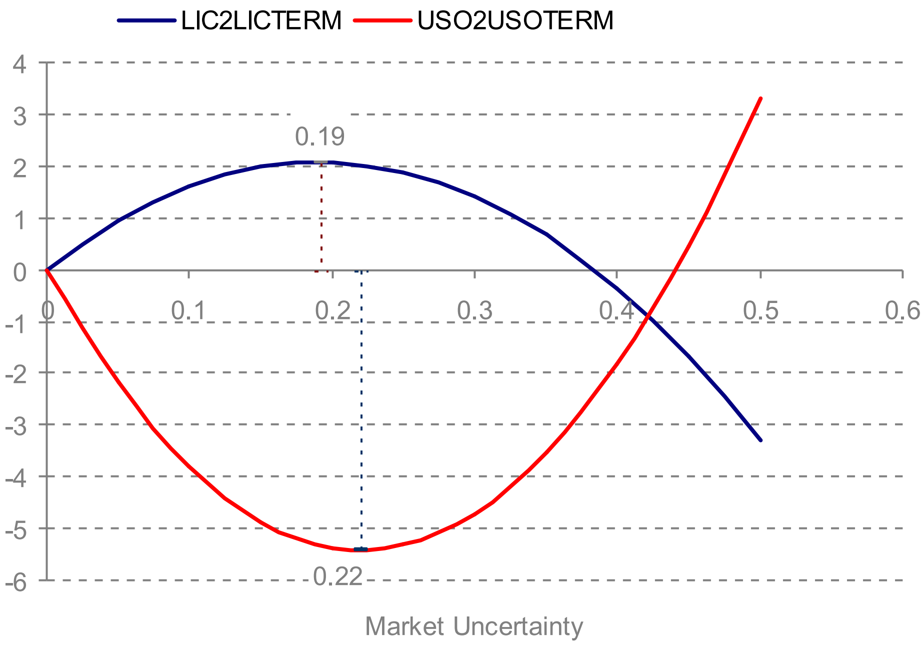
This indicates that endogenous uncertainty as measured by technological uncertainty is much stronger affecting spinning out in a way that inventions that are of high technological uncertainty are much more likely to be commercialized via the spinout route then via the licensing route. The reason for this observation could be that very high technological uncertainty comes along with a high amount of tacit knowledge which is intrinsic to the technology developer i.e. the inventors. Buyers therefore might lack confidence in a highly uncertain technology which could lead the inventors only with one choice and this is to spinout the invention themselves as the market for a highly uncertain technology is not efficient and in some cases does not exist.

Overall the results indicate that the spinout model is much more sensitive to its covariates then the licensing model indicating that extreme covariates lead to the exploitation and commercialization of an invention via the spinout route.

Analyzing the exit decision a competing risk model is not needed since in the spinout failure model the only independent variable that is common in both models is market uncertainty and we have shown already that market uncertainty has inverted influence in the spinout failure and the licensing termination model.

Figure 6-4 shows the effects of market uncertainty for the two models. Looking at the exit we are interested in the option to abandon. This option gets its value when there are sunk costs to entering (in this case R&D costs are sunk costs).

Figure 6-4 Effects of Market Uncertainty on Spinout failure and Licensing termination



Real option theory implies that it is irrational to exit an investment if there is a possibility that the profitability of the investment can increase over time which can be due to the effects of market uncertainty (Dixit 1989). If market uncertainty prevails the chances of a rapid improvement of conditions can quickly alter the investment value positive. Especially with large sunk costs, managers who decided to exit may very well regret that decision because the firm would have to incur those sunk costs all over again in order to re-enter. This leads the decision of the manager to include the significance of the sunk cost of the investment and the potential gain. Continuing the investment and not abandoning it can therefore be profitable. On the other hand maintaining an abandonment option comes with a cost because to keep the investment active running costs like e.g. keeping up a stream of cash flows to pay staff and persist in research and development. Weighing the costs and benefits of the abandonment option and the costs of maintaining it is critical in making the decision to exit or persist with the investment.

This difference of a license and a spinout termination lies in the required cash flow for continuation of the investment. The licensor has a relatively low cost of maintaining the investment and can easily mothball the project if he reaps no profits. The spinout holder has a much larger exposure to the required cash flows and increasing market uncertainty (at moderate levels) would increase the value of his growth options and at the same time limiting the cash flow risk which is correlated to market uncertainty. As soon as volatility levels reach very high values the spinout might be exposed to cash flow problems and might be forced to shut operations whereas the licensor can mothball the project by still keeping minimum payments to the licensor. This would be the optimal decision for him as the option value increases and the costs are kept under control. The owner of a spinout cannot operate under these extreme levels of uncertainty although the growth options might be more valuable but the continuation of business is in jeopardy. This leads to the opposite effect of market uncertainty in the spinout failure and licensing termination scenarios.

As can be seen in Figure 6-4 holding a license and maintaining a spinout provides different exposures to the growth options that can come with persisting the investments. The figure shows a much larger convexity implying that exposure to the growth options in spinouts is much more pronounced then in a licensing contract which is to be expected.

7 Conclusion

7.1 Summary

University commercialization activities usually involve novel technologies that are highly uncertain and the industries which they are evolving in are characterized by a volatile and a rapidly changing environment. Further the technologies are research intensive and exposed to uncertainty regarding their successful development and functionality. On the other hand these technologies have to be absorbed by volatile markets in order to be commercialized. These different forms of uncertainty are of primary importance for decision makers but have not been thoroughly studied in previous research on technology commercialization and put under one theoretical framework. The main focus of this thesis was to comprehend the recently growing trend among universities and public research organizations to commercialize their research activities from an empirical and theoretical perspective. More particularly we have analysed the life cycle of two main commercialization streams namely the entry and exit of university spinouts, which are companies that evolve from intellectual property developed within academic institutions as well as the licensing and licensing termination of inventions. Our main focus of analysis therefore analyses market and technological uncertainty and explains the conditions under which spinout formation, spinout failure, licensing and licensing failure occur by embracing real option theory.

The first part of this thesis analyses thoroughly the existing research streams on the phenomenon of university spinouts from the empirical and theoretical point of view and provides a detailed and structured literature review on this topic by organising the studies under three broad headings (macro- meso- and micro-level studies). Although previous research on spinouts has been mainly accumulative and atheoretical, we show that recently a positive trend towards theory-driven studies is evolving (increasing from 5% to 49% in the past four years) and that the research on this topic is maturing. Further we expect future studies to focus more on analysing performance and to untangle if and where differences exist between spinouts and independent new technology based companies.

We claim that the complexity of the spinout phenomenon due to the different parties, relationships and processes involved makes it an ideal context for testing and extending theory and that there is plenty of scope for further work to untangle and understand these processes thoroughly. Finally we conclude with several research questions that are of strong interest for future theoretical development and propose that the key for future work is to ask the most interesting and practical phenomenon-specific questions but then tackle them with the most theoretical explanations.

The next chapter continues with a detailed overview of the patenting process and patent analysis as well as an introduction of the unique dataset used in this study which contains information on invention disclosures, license agreements and spinouts from the top German public research organization (Max Planck Society) and its 78 research institutes. The contribution of this thesis purely from the data perspective is that it is the first known study to utilize a detailed non American research institution dataset on licensing and spinout activity. The contributions are straightforward since phenomena from prior research streams could be tested and verified and therefore their geographical limitations alleviated. One example finding that was confirmed was the significant influence of technology age on the spinout likelihood, which was used as a control variable in our models and was rigorously tested by Shane (2003).

In the following chapter real option theory was introduced and the justification presented why it is used as an umbrella theory in this thesis. Different theories used in the firm formation/ firm exit literature as well as licensing literature such as transaction cost theory and neoclassical investment theory were presented and parallels and differences to the real option theory drawn. We found that the main difference compared to transaction cost theory is that TCE embraces behavioural uncertainty rather than market and technological uncertainty when explaining the formation and failure of governance structures. Compared to neoclassical investment theory it was shown that unlike the neoclassical investment theory, real option theory embraces uncertainty and gives value to investments with optional characteristics.

Chapter 5 specifically focuses on the effects of market and technological uncertainty on university spinout formation and spinout failure by using a Cox regression to model firm formation and firm failure. We found that market uncertainty is non monotonic in both, the firm formation as well as the firm failure model and influences them with same signs which is consistent with the predictions made by the real option theory. Further we have shown that technological uncertainty increases the likelihood that an invention will be commercialized through firm formation. It was previously discussed that the real option theory does not make any assumptions about the risk preferences of the decision makers i.e. entrepreneurs since it assumes rational decision makers' behaviour. The results in this study show that the decision makers understand the complexity of risk as well as the exact timing when to act on opportunities in order to maximize their value in entry and exit decisions. This makes the real option theory in this context more parsimonious compared to entrepreneurial theories that make assumptions about risk preferences of entrepreneurs. Furthermore, the finding that inventions are more likely to be commercialized through the creation of new firms when the technologies are more uncertain extends the work of strategic management researchers (Tushman and Anderson, 1986) and researchers of technological change (Henderson, 1993). These have argued that new entrants are more likely than incumbents to commercialize radical technologies. This study shows that technological uncertainty also influences the decisions of independent entrepreneurs to create new companies. While previous theorizing on real options suggested that technological uncertainty influences the likelihood and timing of an investment, this study is also the first to provide empirical evidence to support this measure in the context of firm formation and firm failure.

Further the study provides useful implications for the management of the process of spinout creation and support mechanisms to reduce spinout failure. Knowledge of the circumstances under which inventions are more likely to be commercialized through the creation of new organizations and when they are more likely to fail may prove useful in determining university policies toward firm formation and mitigating firm failure. Especially capital availability has been shown to mediate market uncertainty and spinout formation in such a way that in more uncertain markets larger capital availability accentuates spinout formation. This finding could lead to an interesting avenue for future research by better understanding the success of spinouts created in highly uncertain and subsidized environments.

Chapter 6 focuses on the second possible commercialization lifecycle, namely how market and technological uncertainty affect the licensing and licensing termination of an invention. Using a dataset on licensing of public research organisation technologies, the objective of this chapter was to understand how managers use and value real options. The main findings were that market uncertainty has a non monotonic effect on licensing and licensing termination. Although technological uncertainty was not found to be statistically significant in the pre-licensing phase, it was positively influencing the license termination decision.

Contributions to two streams of research are identified, namely the innovation and licensing literature as well as the real option literature. The empirical contribution to innovation literature on technology licensing is such that we identified several mediating effects on uncertainty that affects the likelihood of licensing and licensing termination. This becomes especially important for policy makers who are intending to design support mechanisms for the commercialization of research on both institutional and governmental level. Examples include the mediating effects of technology transfer experience and partnered research efforts which mediate the effects technological uncertainty. Technologies that are uncertain are more likely to be terminated when technology transfer experience is low. The question whether inexperienced technology transfer officers are selling 'hot potatoes' could be an interesting avenue for future research. Further technologies that are more certain are more likely to be licensed when they were developed in partnered research efforts which show the importance of partnering in research and thereby reducing uncertainty. This has a straightforward implication for practise in that policy makers and technology transfer officers should support partnering efforts during the research lifecycle.

Further this research finds support for the theoretical underpinning of real option literature in that it is the first to examine empirically the effects of endogenous and exogenous forms of uncertainty on the licensing and licensing termination likelihood. This empirical justification of real option theory in new areas of research represents an important contribution to the literature as it gives evidence for the applicability of real option reasoning for a wide range of phenomena.

The results of this study also suggest that option value can be firm specific. Firms that have a higher licensing experience and who are more familiar with the process of licensing and technology transfer are more likely to license an invention. This supports findings by Arora and Gambardella (1994) that their internal knowledge base allows firms to be more confident about their decision making in uncertain environments and benefiting from their 'absorptive capacity'.

The implications of this research make a clear contribution to the literature by being the first to empirically investigate different forms of uncertainty not only on the entrance of new high technology firms but also on spinout failure. Further it is the first to study the complete lifecycle of an invention and all its life paths by putting it under one theoretical framework.

7.2 Limitations and future research

Despite the rigorous research approach that was used in this research there are also limitations to the study. Firstly it can be argued that the measure of market uncertainty has its limitations. Previous studies that use market uncertainty in their frameworks differ in the way how market uncertainty is measured, which data is used for its calculation and what time window lengths are used to calculate it. In this paper market uncertainty was calculated using a time windowed measurement of the standard deviation of daily industry index price returns. Previous research does not use a unanimous time window length and is therefore inconclusive on this matter. Rather than looking for uniformity across different research studies, each research study that uses this measure should decide independently based on the average period the decision maker is influenced by in their decision and the be corresponding measurement period should be chosen accordingly. Time frames used in research have ranged from 26 week windows to two year windows. To be exact a 52 week time window to measure market uncertainty was implemented. To mitigate this issue, historical market uncertainties were measured for different window lengths (26 weeks, 52 weeks and 104 weeks) and it was found that the results are valid for all window lengths but less significant for the other time windows.

Further the decision which underlying data to use for the measurement of market uncertainty has been treated differently in previous research. Studies have used industry or firm revenues and GDP data as basis for their volatility measures. This approach was not adopted because GDP and firm revenues are reported in a relatively infrequent basis (usually quarterly). Since decision makers update their decision principles more frequently than once a quarter, more frequent occurring data was required. Therefore it was decided to utilize a similar data source to Folta (1998) who relies on daily stock index data since this data is reliable and very frequent (daily).

The robustness of the market uncertainty measure was further validated by using a separate measure which was used as well by O'Brien et al. (2003). Namely the GARCH(1,1) process was used and fitted to historical data to obtain the market uncertainty measure. This measure was then used as an input to all the models in then thesis and compared to the results obtained with the initial market uncertainty measurement. The detailed results which can be found in the Appendix confirm the stability of all models and do not alter the results for any of the variables significantly. On the contrary for the invention to license model the model constructed with the GARCH(1,1) volatility measure seems to be even more robust when compared to using the historical uncertainty measure.

As already mentioned the thesis measures market uncertainty on an industry level and theorizes that industry specific market uncertainty influences firm formation, firm failure, licensing propensity and licensing failure as predicted by the real option theory. It is known that volatility is clustered and correlated across markets (Engle, 1982) and it would be interesting to understand if the impact of uncertainty in the decision making process is really industry specific or if the decision makers are influenced by the uncertainty of the market as a whole. This would enable improved understanding if decision makers really consider cross sectional uncertainty when making their decisions or are influenced only by their own industries' uncertainty bubble.

It would as well be interesting to see future studies utilizing the technological uncertainty measure constructed in this study by deploying it and applying it to other phenomena.

An important avenue for future research is a better understanding of the mitigating effects on uncertainty. Do decision makers that have an advantage in accessing resources, superior experience in exercising an option and who receive better support mechanisms, estimate the uncertainty in a dissimilar manner and therefore value the option differently? Understanding this question would clarify the question if the real option value is subjective to the decision maker and if the decision makers' perception of uncertainty can be moderated. Being able to answer this question could bring the transaction cost theory which focuses on transactional asset specificity a step closer to the real option framework by introducing optional asset specificity that can have a real impact on real option valuation. This finding would also have a direct impact on the policy makers who are interested in encouraging entrepreneurship or commercialization of research. By understanding how uncertainty can be mitigated, stimulation policies could be designed accordingly.

A further limitation in the firm formation model is that the study recognizes patents as the only source of opportunities and neglects other e.g. uncodified innovations or non patentable innovations as a source of opportunities that can lead to firm formation. If the difference between coded (patents) and uncoded technological opportunities is systematic, the study might not be generalizable to all technological innovations and how high technology firm formation can be explained in the context that was presented in this study. Future research might address this issue by analysing specifically the characteristics of patents and other not codified innovations in order to understand if their characteristics differ.

Further it was presumed that termination of licenses occurs due to market or technological failure. However when property rights are week, licensees may decide to abandon the license and invent around the invention which was also observed by (Dechenaux et al., 2003). It was not possible to control for this scenario in this thesis.

The study focuses only on patents and spinouts from one research institution making patenting, licensing, firm formation and firm failure solely dependent on the parent institution and the entrepreneurs that stem from the parent institution to commercialize the intellectual property in form of a spinout. Still, Max Planck Society is a highly diverse research institution consisting of more than 50 independently operating institutes where the decision to file for a patent or form a spinout is not solely driven by one and the same organizational entity. Still it cannot be excluded that firm formation or failure rates for inventions that are patented by MPS are different from those inventions patented by other universities or research institutions. If this systematic difference exists a generalizations may not be possible.

Future work should therefore try to validate these findings by extending the research to different or a larger number of institutions to generalize the findings. This research has primarily focused on the market-wide factors that influence the value of real options. An area for further research could be to investigate factors on the institution-level that might influence the value of technological options they plan to pursue. Such institution-level factors may help to understand how different institutions are coping with exogenous and endogenous uncertainty in order to optimize their technology commercialization outcomes.

Another interesting future research stream would be to better understand the way option portfolios are constructed and held by licensees. Is the reason why firms license patents in areas close to their patenting focus to strengthen their option portfolio or to prevent competitors gaining deeper knowledge in their areas of expertise? Further it would be interesting to understand how firms go about licensing patents in more technologically distant areas from their own patent focus. Is it driven by reasons of exploration and thereby reducing technological uncertainty in this technological area by proactively investing in it and learning about the technology? Or is it more about diversifying risk and market uncertainty of their innovation base? Questions like this would provide great insight in how licensees actively try to mitigate risk and how they are trying to optimize their option portfolio.

Furthermore, in the post licensing phase it was not possible to track empirically the event of first sale of a license since the data was not available at this point in time but only data on the termination timing of licenses. It is believed that the empirics would follow the theory and that market and technological uncertainties would affect the first sale of a license in the same way as the licensing study suggests. Further research could elaborate on this point empirically and test these hypotheses.

Despite the mentioned limitations, empirical evidence was provided that endogenous and exogenous uncertainty affects the rate of firm formation and firm failure rates as well as licensing and licensing termination rates. It has to be noted that resemblance was found between this study and the results of other studies that analyze spinout formation and firm failure and utilize similar datasets. Although the settings and location of this study is very different to the existing studies on spinout formation (mostly on US universities), the resemblance brings confidence to the results of both studies.

Although there are certain limitations to this study evidence was provided that different forms of uncertainty affect real options differently throughout their innovation lifecycle. The results contribute to the growing literature on commercialization from public research organizations and universities (Djokovic and Souitaris, 2008) and provide evidence on the commercialization efforts under diverse forms of uncertainty.

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9 Appendix

9.1 Robustness of Market Uncertainty Measure

Two different approaches were conducted to validate the robustness of the market uncertainty measure. The first approach alternates the time window length used in the calculation of historical market uncertainty and the second approach calculates market uncertainty using a completely different method, namely fitting a GARCH(1,1) model through the daily index return data.

The first approach is a rather trivial robustness check and validates the time period used rather than the measure itself. Different time windows measurements were used, namely 26 weeks, 52 weeks and 104 weeks. Table 9-1 shows that using different time window lengths do not alter the model results significantly. This leads to the conclusion that the model is rather insensitive to the length time window used.

Table 9-1 Overall Model significances for different time window lengths of the historical market uncertainty measure

Model	26 weeks	52 weeks	104 weeks
Invention to Spinout	***	***	***
Spinout to Spinout Termination	***	***	***
Invention to License	***	***	***
License to License Termination	***	***	***

† $p < 0.1$
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

The second approach to validate robustness is to construct a separate uncertainty measure and compare the model fit with the existing measure (i.e. historical volatility). A powerful time series technique to model volatility is the GARCH(p,q) framework which will be used as the second measure of market uncertainty. GARCH stands for Generalized Autoregressive Conditional Heteroscedasticity and it allows the modelling of conditional time varying volatility. Heteroscedasticity refers in statistics to random variables that have different variances across time. Conditional implies a dependence on the observations of the immediate past, and autoregressive describes a feedback mechanism that incorporates past observations into the present. GARCH enables the statistician therefore to include past volatilities in the explanation of future volatilities and in this way allows the modelling of serial dependence of volatility. It can be represented in following way:

$$\sigma_t^2 = \alpha_0 + \alpha_1 \epsilon_{t-1}^2 + \cdots + \alpha_q \epsilon_{t-q}^2 + \beta_1 \sigma_{t-1}^2 + \cdots + \beta_p \sigma_{t-p}^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i \sigma_{t-i}^2$$

where ϵ_t denote the error terms and σ_t the standard deviation. The parameters α and β are usually fitted using maximum likelihood estimation. In this study a GARCH(1,1) model was used to fit the daily index returns which sets parameters $p = 1$ and $q = 1$ in the model.

9.1.1 Model Comparison Historical vs. GARCH

The following tables compare all models used in this thesis for the historical volatility measure and GARCH volatility estimation. It becomes clear that not one coefficient of the model inputs changes sign or significance level. The only exception is in the 'spinout to spinout termination' model where the significance of the market uncertainty measure drops but is still inside the 0.1 significance level. On the other hand the GARCH uncertainty measure improves the 'invention to license' model in such way that the significance of market uncertainty and squared market uncertainty increases. Overall this model comparison shows that the current market uncertainty measure in itself is robust as well as the models estimated in this thesis.

Table 9-2 Invention to Spinout Model Comparison (Historical vs. GARCH)

Variables	**Historical Uncertainty**		**GARCH Uncertainty**	
	B	**Sig.**	**B**	**Sig.**
Mechanical	1.776	0.133	1.558	0.179
Chemical	2.031	0.115	1.858	0.132
Pharma & Bio	1.972	0.155	1.793	0.172
Medical	3.648	0.004	3.322	0.009
Year Issued	0.653	0.003	0.559	0.010
Patent Quality	0.005	0.019	0.005	0.015
Patent Scope	0.003	0.934	0.001	0.980
Technology Age	-0.033	0.001	-0.031	0.002
Firm Size	0.009	0.158	0.008	0.191
R&D Intensity	-0.210	0.147	-0.207	0.148
Capital Availability	0.002	0.054	0.003	0.020
Market Uncertainty	-22.803	0.013	-19.834	0.044
Market Uncertainty Square	59.978	0.002	50.036	0.006
Technological Uncertainty	0.451	0.001	0.448	0.002

Table 9-3 Spinout to Spinout Termination Model Comparison (Historical vs. GARCH)

Variables	Historical Uncertainty		GARCH Uncertainty	
	B	**Sig.**	**B**	**Sig.**
Mechanical	0.163	0.924	0.778	0.701
Chemical	2.142	0.534	3.121	0.389
Pharma & Bio	5.125	0.256	6.542	0.185
Medical	-16.682	0.980	-16.339	0.981
Conceptual Support	0.786	0.207	0.708	0.251
Business Plan Support	-0.433	0.638	-0.456	0.610
Financial Planning Support	-0.044	0.960	0.043	0.961
Licence Support	-0.561	0.534	-0.818	0.350
Equity Support	1.872	0.120	1.790	0.139
External Financing	-2.924	0.004	-2.706	0.007
University Cooperation	-3.447	0.012	-3.399	0.012
Industry Cooperation	-3.091	0.007	-2.889	0.014
MPG Cooperation	-0.301	0.660	-0.155	0.813
Firm Size	-0.032	0.175	-0.036	0.148
R&D Intensity	1.021	0.025	1.057	0.021
Capital Intensity	-0.005	0.718	-0.004	0.793
Capital Availability	0.008	0.007	0.007	0.011
Market Uncertainty	-49.147	0.006	-36.892	0.079
Market Uncertainty Square	111.545	0.007	67.858	0.058

Table 9-4 Invention to License Model Comparison (Historical vs. GARCH)

Variables	Historical Uncertainty		GARCH Uncertainty	
	B	**Sig.**	**B**	**Sig.**
Mechanical	-0.280	0.433	-0.276	0.450
Chemical	0.192	0.425	0.269	0.296
Pharma & Bio	0.148	0.542	0.175	0.498
Medical	0.239	0.361	0.184	0.505
Patent References	0.026	0.049	0.026	0.046
Patent Quality	0.002	0.298	0.002	0.328
Patent Scope	-0.005	0.774	-0.004	0.810
Technology Age	-0.005	0.249	-0.005	0.228
Funded Research	-0.017	0.928	-0.032	0.867
Partnered Research	0.999	0.000	1.001	0.000
Invention Experience	0.203	0.938	0.049	0.985
Licensee Experience	0.007	0.014	0.007	0.014
Tech. Trans. Experience	0.002	0.381	0.001	0.468
Market Uncertainty	12.361	0.012	14.759	0.003
Market Uncertainty Square	-27.947	0.033	-23.239	0.011
Technological Uncertainty	0.054	0.269	0.057	0.247
Threat of Preemption	-0.196	0.024	-0.197	0.024

Table 9-5 License to License Termination Model Comparison (Historical vs. GARCH)

Variables	Historical Uncertainty		GARCH Uncertainty	
	B	**Sig.**	**B**	**Sig.**
Mechanical	-0.236	0.764	-0.070	0.929
Chemical	0.201	0.596	0.602	0.133
Pharma & Bio	0.104	0.750	0.603	0.087
Medical	-0.057	0.882	0.253	0.521
Year Issued	1.229	0.000	1.220	0.000
Patent References	0.035	0.145	0.035	0.135
Patent Quality	-0.010	0.078	-0.010	0.068
Patent Scope	-0.065	0.073	-0.069	0.058
Technology Age	-0.005	0.467	-0.005	0.472
Funded Research	0.724	0.034	0.686	0.045
Partnered Research	-1.703	0.000	-1.701	0.000
Previous Inventions	0.020	0.010	0.022	0.006
Previous Licensee	-0.018	0.041	-0.021	0.021
Previous TT Experience	-0.001	0.727	-0.001	0.905
Market Uncertainty	21.710	0.009	14.550	0.007
Market Uncertainty Square	-56.577	0.025	-21.318	0.031
Technological Uncertainty	0.151	0.036	0.151	0.036

9.1.2 Volatility Measurement Comparison across Industries

The following figures show the historical and GARCH market uncertainty measures across time. It becomes evident that the pattern of both measures is very similar for all industry sector estimations. One important observation is that the GARCH uncertainty measure is very sensitive compared to the historical uncertainty measure. This is because it is fitted on a daily basis and every price spike in the underlying index leads to a volatility spike. To mitigate these spikes a filter was used to smoothen the GARCH results. The reason for this from an empirical perspective is that decision makers are not making entry and exit decisions based on a daily volatility spike but rather consider longer term uncertainty environments. Therefore a simple moving average was fitted to the daily GARCH estimation to smoothen it. The period of the simple moving average was chosen to coincide with the period used to calculate the historical uncertainty measure. It should be noted that the filtered GARCH volatilities rather than the raw GARCH volatilities were used as an input into all models discussed in the previous chapter.

Figure 9-1: Historical vs. GARCH Market Uncertainty (Electrical)

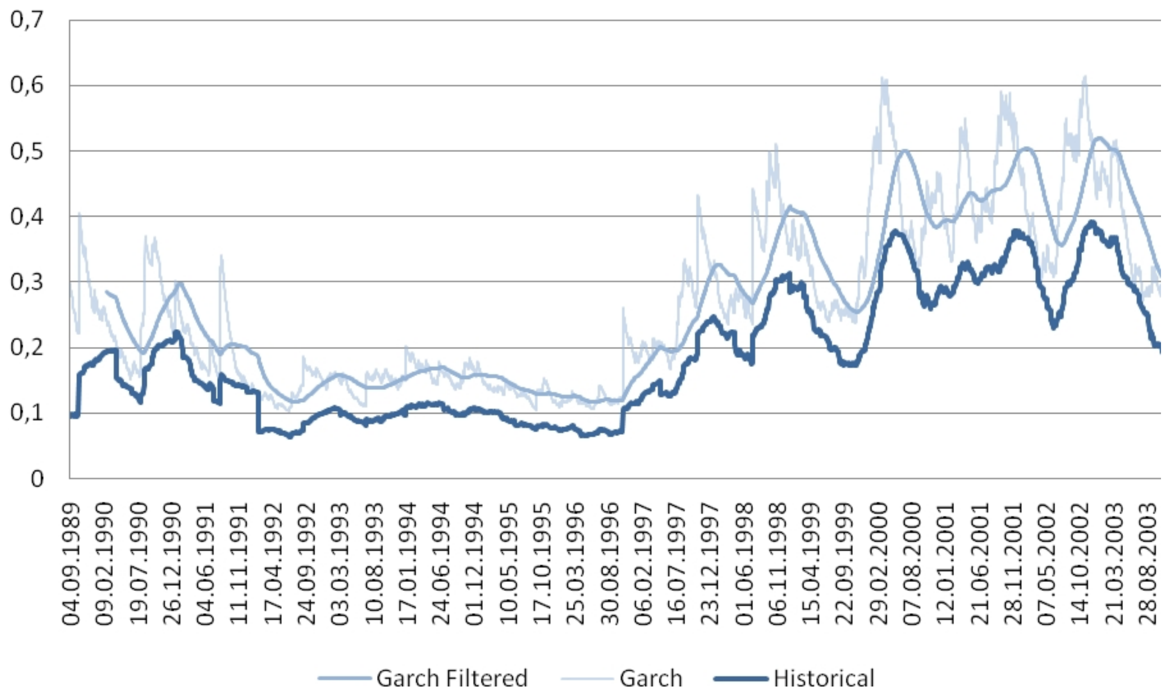


Figure 9-2: Historical vs. GARCH Market Uncertainty (Mechanical)

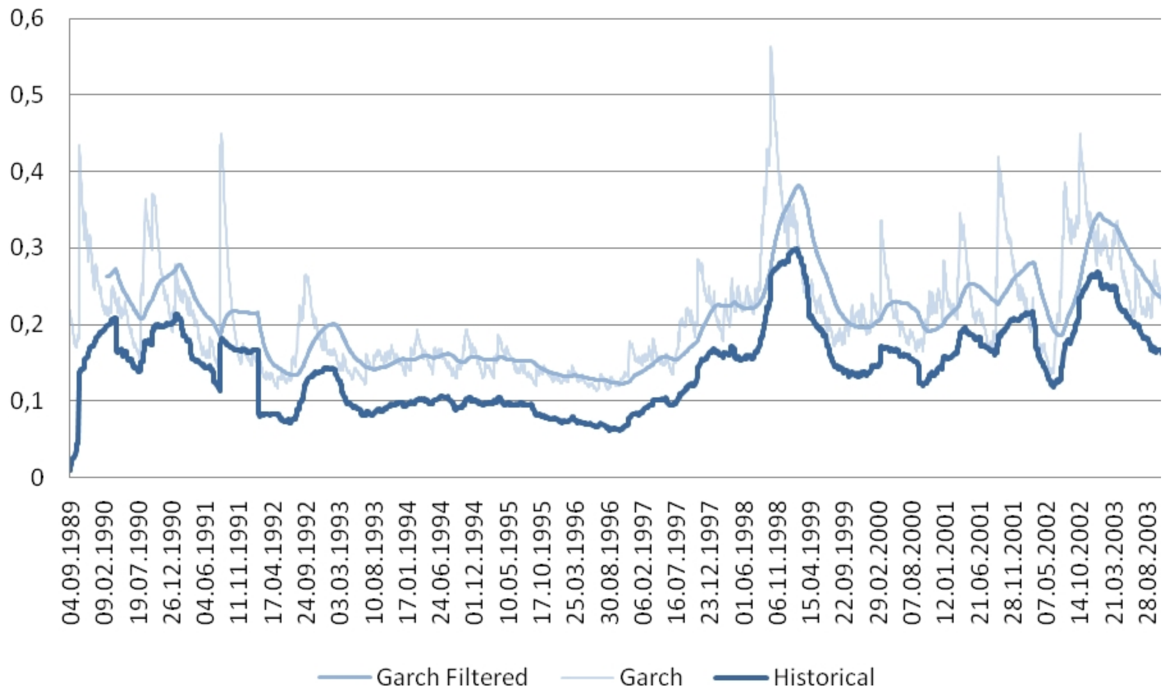


Figure 9-3: Historical vs. GARCH Market Uncertainty (Chemical)

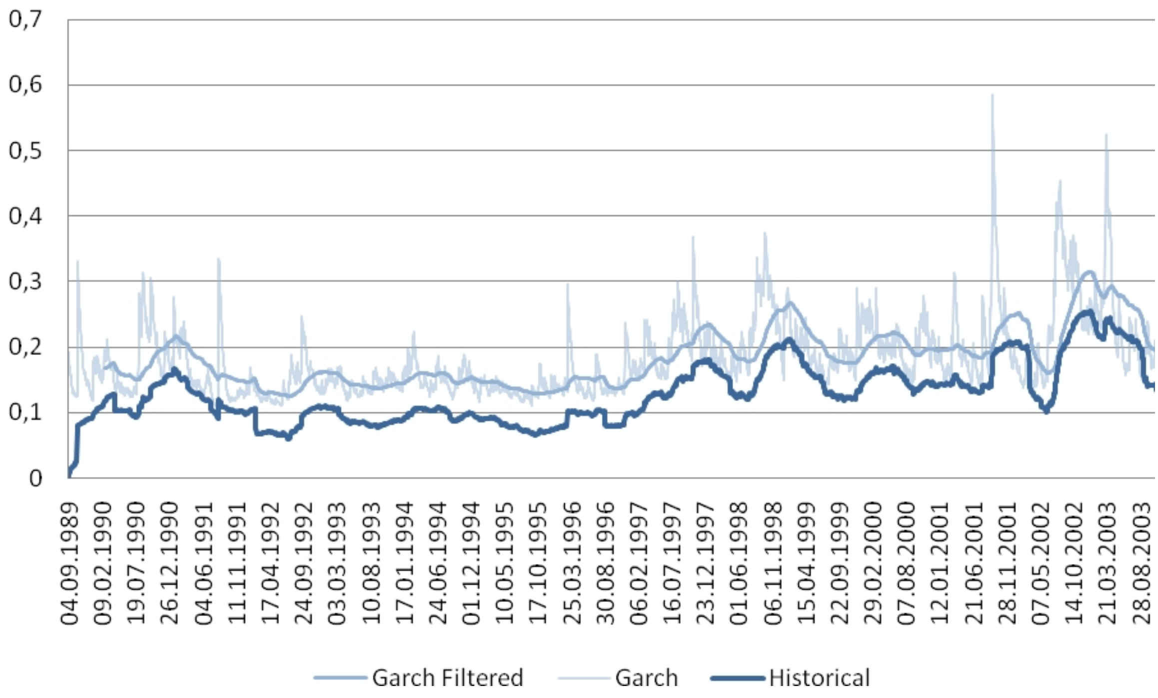


Figure 9-4: Historical vs. GARCH Market Uncertainty (PharmaBio)

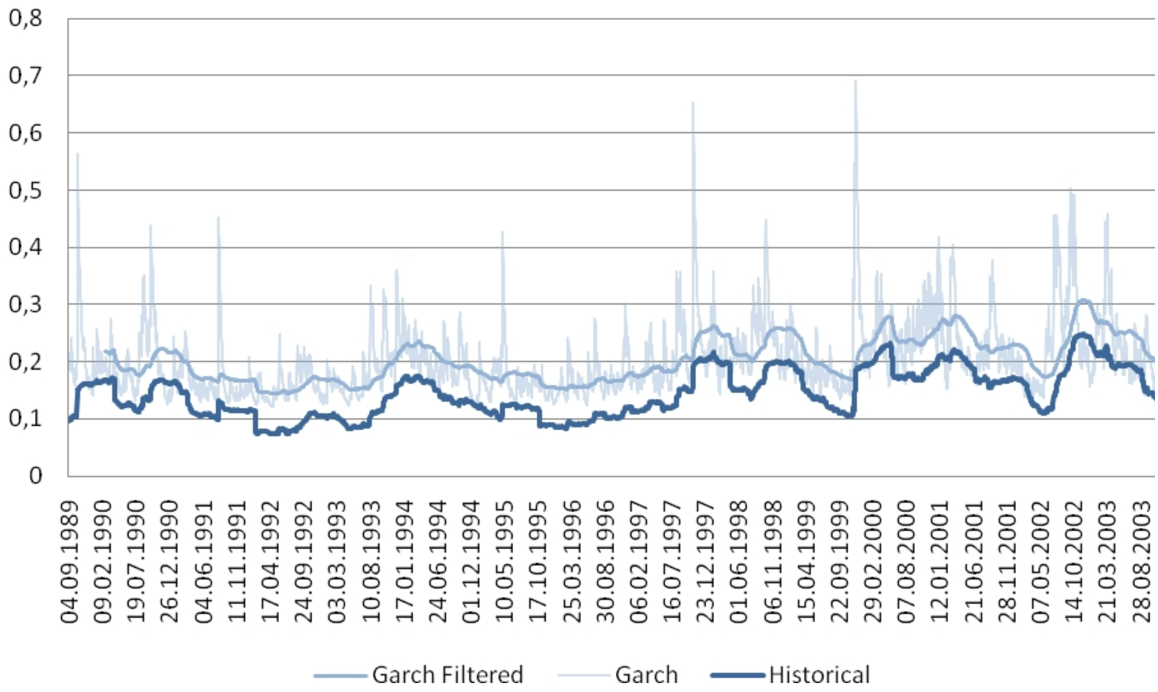
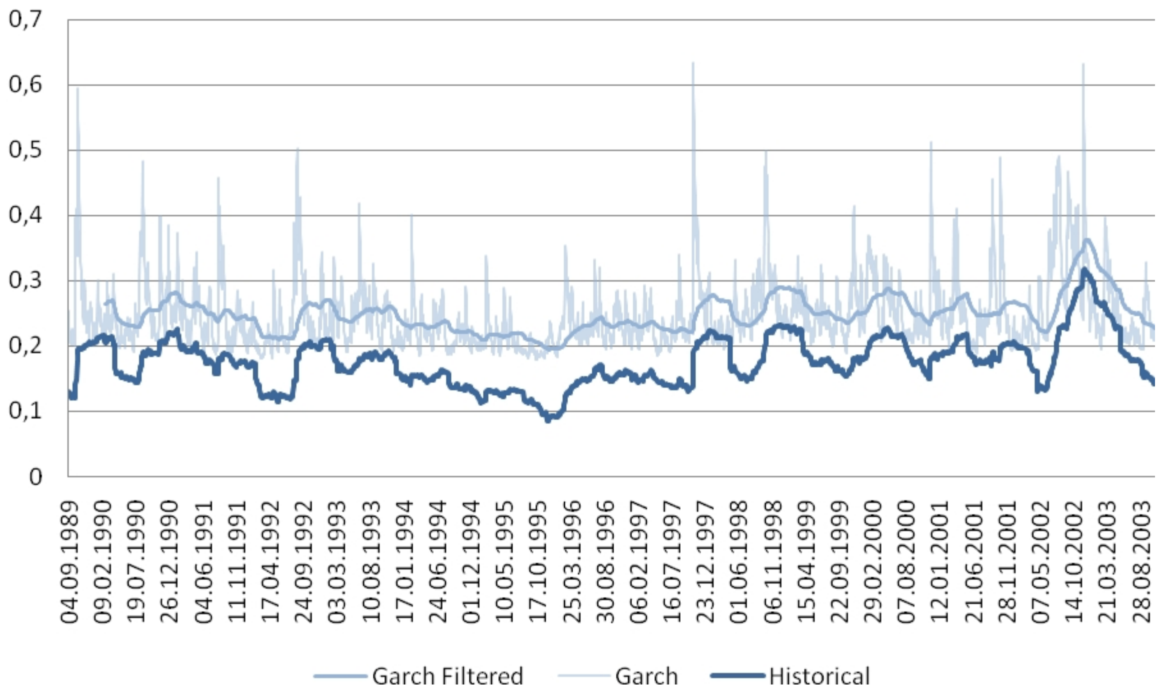


Figure 9-5: Historical vs. GARCH Market Uncertainty (Medical)



9.2 Spinout Literature Classification

Table 9-6: Index list of the spinout papers identified

Primary Spinout Literature						
T	E	QL	The strength of strong ties: University spin-offs and the significance of historical relations	Johansson et.al.	2005	The Journal of Technology Transfer
P	C		Entrepreneurship and university technology transfer	Wright et.al.	2005	The Journal of Technology Transfer
T	E	QN	R&D networks and product innovation patterns-academic and non-academic new technology-based firms on science parks	Lindelöf and Löfsten	2005	Technovation
P	E	QN	Assessment of proposals for new technology ventures in the UK: Characteristics of university spin-off companies	De Coster	2005	Technovation
P	E	QL	The process of transformation of scientific and technological knowledge into economic value conducted by biotechnology spin-offs	Fontes	2005	Technovation
T	C		The creation of spin-off firms at public research institutions: Managerial and policy implications	Lockett et.al.	2005	Research Policy
T	E	QN	Resources, capabilities, risk capital and the creation of university spin-out companies	Lockett and Wright	2005	Research Policy
T	E	QN	Opening the ivory tower's door: An analysis of the determinants of the formation of U.S. university spin-off companies	Link and Scott	2005	Research Policy
T	E	QN	Entrepreneurial orientation, technology transfer and spin-off performance of U.S. universities	O'Shea et.al.	2005	Research Policy
P	E	QL	Academic entrepreneurship: Assessing preferences in nascent entrepreneurs	Brennan et.al.	2005	J. of Small Business and Enterprise Development
T	E	QN	University start-up formation and technology licensing with firms that go public: A resource-based view of academic entrepreneurship	Powers and McDougall	2005	Journal of Business Venturing;
T	E	QN	Academics' organizational characteristics and the generation of successful business ideas	Grandi and Grimaldi	2005	Journal of Business Venturing
P	E	QL	Growth inhibitors of entrepreneurial academic spin-offs	Tahvanainen	2005	Int. J. of Innovation and Technology Management
P	E	QL	Higher education excellence and local economic development: The Case of the entrepreneurial University of Twente	Lazzeretti and Tavoletti	2005	European Planning Studies
P	C		University spin-off policies and economic development in less successful regions: Learning from two decades of policy practice	Benneworth and Charles	2005	European Planning Studies
P	E	QN	The evolution and performance of biotechnology regional systems of innovation	Niosi and Banik	2005	Cambridge Journal of Economics
P	C		Universities and technology transfer: A review of academic entrepreneurship literature	O'Shea et.al.	2005	Irish Management Journal
T	E	QL	Maximising the potential of university spin-outs: The development of second order commercialisation activities	Leitch and Harrison	2005	R & D Management
P	E	QL	An empirical study of university spin-off development	Gübeli and Doloreux	2005	European Journal of Innovation Management
T	E	QN	Incubator firm failure or graduation? The role of university linkages	Rothaermel and Thursby	2005	Research Policy
T	E	QL	A process study of entrepreneurial team formation: The case of a research-based spin-off	Clarysse and Moray	2004	Journal of Business Venturing
T	E	QL	Critical junctures in the development of university high-tech spinout companies	Vohora et.al.	2004	Research Policy
T	E	QL	Do academic spin-outs differ and does it matter?	Druilhe and Garnsey	2004	The Journal of Technology Transfer
P	E	QL	Overcoming weak entrepreneurial infrastructures for academic spin-off ventures	Degroof and Roberts	2004	The Journal of Technology Transfer
T	E	QN	Proximity as a resource base for competitive advantage: University-industry links for technology transfer	Lindelöf and Löfsten	2004	The Journal of Technology Transfer
P	C		The management of financial resources to sustain the academic incubators of entrepreneurial ideas	Corti and Torello	2004	Int. J. of Entr. & Innovation Management
T	C		Academic networks in a trichotomous categorisation of university spinouts	Nicolaou and Birley	2003	Journal of Business Venturing
P	C		Business model fashion and the academic spinout firm	Bower	2003	R & D Management
T	E	QN	Exploring the networking characteristics of new venture founding teams	Grandi and Grimaldi	2003	Small Business Economics
T	E	QN	Social networks in organizational emergence: The university spinout phenomenon	Nicolaou and Birley	2003	Management Science
P	E	QN	Technology transfer and universities' spin-out strategies	Lockett et.al.	2003	Small Business Economics
P	E	QN	The development of university spin-offs: Early dynamics of technology transfer and networking	Perez and Sanchez	2003	Technovation
P	C		Toward a typology of university spin-offs	Pirnay et.al.	2003	Small Business Economics

P	C		Universities, academics, and spinout companies: Lessons from Imperial	Birley	2003	Int. J. of Entrepreneurship Education
P	E	QN	Why do some universities generate more start-ups than others?	Di Gregorio and Shane	2003	Research Policy
P	C		A stage model of academic spin-off creation	Ndonzuau et.al.	2002	Technovation
T	E	QN	Equity and the technology transfer strategies of American research universities	Feldman et.al.	2002	Management Science
T	E	QN	Organizational endowments and the performance of university start-ups	Shane and Stuart	2002	Management Science
P	C		Matching technology push to market pull: Strategic choices and the academic spinout firm	Bower	2002	Int. J. of Entr. and Innovation Management
P	E	QN	Supporting university enterprise: The Scottish and US experience	Smailes et.al.	2002	Int. J. of Entr. and Innovation Management
P	E	QN	Academic and surrogate entrepreneurs in university spinout companies	Franklin et.al.	2001	Journal of Technology Transfer
P	E	QL	Lessons learned about technology transfer	Rogers et.al.	2001	Technovation
T	E	QN	Technology regimes and new firm formation	Shane	2001	Management Science
P	E	QN	Exploitation and diffusion of public research: The case of academic spin-off companies in Italy	Chiesa and Piccaluga	2000	R & D Management
P	E	QL	Spin-offs from research centers at a research university	Steffensen et.al.	2000	Journal of Business Venturing
P	E	QN	University revenues from technology transfer: Licensing fees vs. equity positions	Bray and Lee	2000	Journal of Business Venturing
P	E	QN	Making sense of diversity and reluctance: Academic-industrial relations and intellectual property	Rappert et.al.	1999	Research Policy
P	E	QL	High-technology spin-offs from government R&D laboratories and research universities	Carayannis et.al.	1998	Technovation
P	E	QN	Public sector entrepreneurship in Central and Eastern Europe: A study of academic spin-offs in Hungary and Bulgaria	Dylan et.al.	1998	Journal of Applied Management Studies
P	E	QN	Spinoff enterprises: How French academics create high-tech companies: The conditions for success or failure	Mustar	1997	Science and public policy
P	E	QL	Stimulation of technology-based small firms - A case study of university-industry cooperation	Klofsten and Dylan	1996	Technovation
P	E	QL	Policies and structures for spinning off new companies from research and development organizations	Roberts and Malone	1996	R & D Management
P	E	QL	Faculty entrepreneurship and economic development: The case of the University of Calgary	Chrisman et.al.	1995	Journal of Business Venturing
P	C		A model for entrepreneurial spinoffs from public technology resources	Radosevich	1995	Int. J. of Technology Management
P	E	QN	The technological base of the new enterprise	Roberts	1991	Research Policy
P	E	QN	University spin-out companies: Technology start-ups from UT-Austin	Smilor et.al.	1990	Journal of Business Venturing
P	E	QN	Growth pattern of academic entrepreneurial firms	Doutriaux	1987	Journal of Business Venturing
P	C		The role of the research university in the spin-off of high-technology companies	Rogers	1986	Technovation
P	C		A proposed mechanism for commercializing university technology	Brown	1985	Technovation
P	E	QN	Spin-off companies from Chalmers University of Technology	McQueen and Wallmark	1982	Technovation
Secondary Spinout Literature						
			Innovation speed: Transferring university technology to market	Markman et.al.	2005	Research Policy
			Analyzing the Effectiveness of University Technology Transfer: Implications for Entrepreneurship Education	Siegel and Phan	2005	Colloquium on Entr. Education and Technology
			University-industry collaborations in Japan: The role of new technology-based firms in transforming the National Innovation System	Motohashi	2005	Research Policy
			Academic entrepreneurship: Case study of Australian universities	Zhao	2004	Int. J. of Entrepreneurship & Innovation
			Governments and universities as the main drivers of enhanced Australian university research commercialisation capability	Harman and Harman	2004	Journal of Higher Education Policy & Man.
			Academic entrepreneurs or entrepreneurial academics? Research-based ventures and public support mechanisms	Meyer	2003	R & D Management
			Bottom-up versus top-down policies towards the commercialization of university intellectual property	Goldfarb and Henrekson	2003	Research Policy
			Commercial knowledge transfers from universities to firms: Improving the effectiveness of university-industry collaboration	Siegel et.al.	2003	Journal of High Technology Man. Research
			Policies to stimulate regional innovation capabilities via university-industry collaboration: An analysis and an assessment	Van Looy et.al.	2003	R & D Management
			Research groups as 'quasi-firms': The invention of the entrepreneurial university	Etzkowitz	2003	Research Policy
			The product market and the market for "ideas": Commercialization strategies for technology entrepreneurs	Gans and Stern	2003	Research Policy
			Towards hybrid Triple Helix indicators: A study of university-related patents and a survey of academic inventors	Meyer et.al.	2003	Scientometrics
			Executive Forum: University technology transfer to entrepreneurial companies	Shane	2002	Journal of Business Venturing
			Links and impacts: The influence of public research on industrial R&D	Cohen et.al.	2002	Management Science
			Selling university technology: Patterns from MIT	Shane	2002	Management Science

	Testing the effectiveness of organizational practices in university technology transfer programs	Colwell	2002	Academy of Management Proceedings
	Designing efficient institutions for science-based entrepreneurship: Lesson from the US and Sweden	Henrekson and Rosenberg	2001	Journal of Technology Transfer
	Evaluation of projects and determinants of success	Meseri and Maital	2001	Journal of Technology Transfer
	Proofs and prototypes for sale: The tale of university licensing	Jensen and Thursby	2001	American Economic Review
	Comparing academic entrepreneurship in Europe: The Case of Sweden and Ireland	Klofsten and Dylan	2000	Small Business Economics
	Technology transfer and the research university a search for the boundaries of university industry collaboration	Lee	2000	Research Policy
	The future of the university and the university of the future: Evolution of ivory tower to entrepreneurial paradigm	Etzkowitz et.al.	2000	Research Policy
	Secrets of success and failure in commercializing US government R&D laboratory technologies	Carayannis and Jeffrey	1999	International Journal of Technology Management
	Growing the Linkoping technopole - A longitudinal study of triple helix development in Sweden	Klofsten et.al.	1999	Journal of Technology Transfer
	Partnerships, configurations and dynamics in the creation and development of SMEs by researchers	Mustar	1998	Industry and Higher Education
	The norms of entrepreneurial science cognitive effects of the new university industry linkages	Etzkowitz	1998	Research Policy
	Growth and inventiveness in technology-based spin-off firms	Dahlstrand	1997	Research Policy
	Inventions and patents at universities: The case of Chalmers University of Technology	Wallmark, J Torkel	1997	Technovation
	Mapping the university technology transfer process	Harmon	1997	Journal of Business Venturing
	Regimes of ordering: The commercialization of intellectual property in industrial-academic collaborations	Rappert and Webster	1997	Technology Analysis & Strategic Management
	Commercialization of university research: A policy perspective	Lowe	1993	Technology Analysis & Strategic Management
	Conflicts in the commercialization of knowledge: Perspectives from science and entrepreneurship	Bird et.al.	1993	Entrepreneurship Theory and Practice
	Universities and the start-up of new companies: Can we generalize from Route 128 and Silicon Valley?	Bania et.al.	1993	Review of Economics and Statistics
	University scientists as entrepreneurs	Richter	1993	Technovation
	University technology transfers: Impacts on local and US economies	Parker and Zilberman	1993	Contemporary Policy Issues
	Universities as engines of R&D-based economic growth: They think they can	Feller	1990	Research Policy
	University innovation centres and academic venture formation	McMullan and Melnyk	1988	R & D Management
	Motivational factors influencing high-technology entrepreneurship	Corman et.al.	1987	Journal of Small Business Management
	Universities and technological entrepreneurship in Britain: Some implications of the Cambridge phenomenon	Segal	1987	Technovation
	Contrasts in the role of incubators organizations in the founding of growth oriented firms	Cooper	1984	Frontiers of Entrepreneurship Research
	A Canadian university experience in technological innovation and entrepreneurship	Hay	1981	Technovation
	Acquiring and selling technology-licensing sources and resources	Senkus	1979	Research Management
	Spin-off companies and technical entrepreneurship	Cooper	1971	IEEE Transactions on Engineering Management
	Legend for the Primary spinout literature: P (phenomenon-focused study) vs. T (theory-driven study) E (empirical study) vs. C (conceptual) QN (quantitative study) vs. QL (qualitative study)			

9.3 MPS Dataset

9.3.1 Overview

The following table shows a detailed descriptive comparison between all variables used in the models. Further the table depicts the number of cases and events that each model entails. It is logical that the number of events (spinouts = 82) in the invention to spinout model equals the number of cases (spinouts = 82) in the spinout to spinout termination model since the dataset for both models is complete. On the other hand the number of cases (inventions = 950) in the invention to spinout model does not equal the number of cases (inventions = 1123) in the invention to license model. The reason is that an invention can be licensed to a number of different companies. So each invention can lead to multiple licenses. For the invention to spinout model we only consider one invention as being valid to be absorbed by a spinout and therefore disregard the multiple cases in this model. This reduces the number of cases from 1123 to 950 in the invention to spinout model.

Table 9-7: Descriptive Statistics of Models

	Invention to Spinout				Spinout to Spinout Termination				Invention to License				License to License Termination			
Number of Cases	950				82				1123				484			
Number of Events	82				26				383				146			
	Min	**Max**	**Mean**	**StDev**	**Min**	**Max**	**Mean**	**StDev**	**Min**	**Max**	**Mean**	**StDev**	**Min**	**Max**	**Mean**	**StDev**
Mechanical	0.00	1.00	0.07	0.25	0.00	1.00	0.06	0.24	0.00	1.00	0.06	0.24	0.00	1.00	0.03	0.16
Chemical	0.00	1.00	0.28	0.45	0.00	1.00	0.12	0.33	0.00	1.00	0.27	0.44	0.00	1.00	0.24	0.43
Pharma & Bio					0.00	1.00	0.62	0.49	0.00	1.00	0.44	0.50	0.00	1.00	0.55	0.50
Medical	0.00	1.00	0.09	0.29	0.00	1.00	0.02	0.16	0.00	1.00	0.10	0.30	0.00	1.00	0.11	0.32
Year Issued	0.00	1.00	0.47	0.50					0.00	1.00	0.48	0.50	0.00	1.00	0.58	0.49
Patent Quality	0.00	613.00	18.82	26.39					0.00	613.00	18.48	25.32	0.00	613.00	20.25	34.90
Patent Scope	0.00	19.00	2.55	2.75					0.00	19.00	2.63	2.77	0.00	19.00	3.12	3.01
Technology Age	0.00	77.33	16.57	13.13					0.00	77.33	15.96	13.06	0.00	72.97	13.29	12.42
Firm Size	71.00	502.00	343.41	118.03	71.02	479.05	363.63	103.04								
R&D Intensity	250	10884	4573	2785	6116	190539	95374	47723								
Capital Availability	0.00	352.44	47.42	92.91	0.00	352.44	96.94	125.76								
Threat of Preemption									0.77	6.12	2.62	0.76				
Market Uncertainty	0.10	0.49	0.21	0.07	0.08	0.36	0.17	0.06	0.06	0.37	0.15	0.05	0.07	0.38	0.16	0.05
Technological Uncertainty	-9.13	0.00	-1.20	1.33					-9.13	0.00	-1.15	1.28	-7.59	0.00	-1.87	1.42
Conceptual Support					0.00	1.00	0.50	0.50								
Business Plan Support					0.00	1.00	0.44	0.50								
Financial Planning Support					0.00	1.00	0.37	0.48								
Licence Support					0.00	1.00	0.30	0.46								
Equity Support					0.00	1.00	0.30	0.46								
External Financing					0.00	1.00	0.38	0.49								
University Cooperation					0.00	1.00	0.37	0.48								
Industry Cooperation					0.00	1.00	0.32	0.47								
MPG Cooperation					0.00	1.00	0.09	0.28								

9.3.2 Event Frequency Summary

Figure 9-6: Spinout and Spinout Termination Event Frequency Histogram

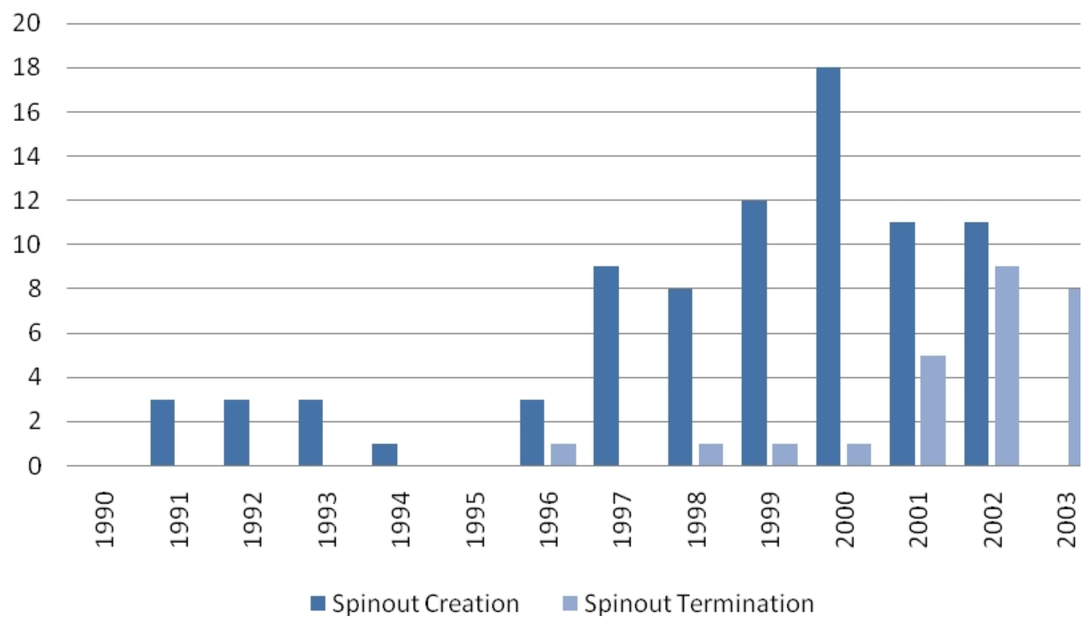
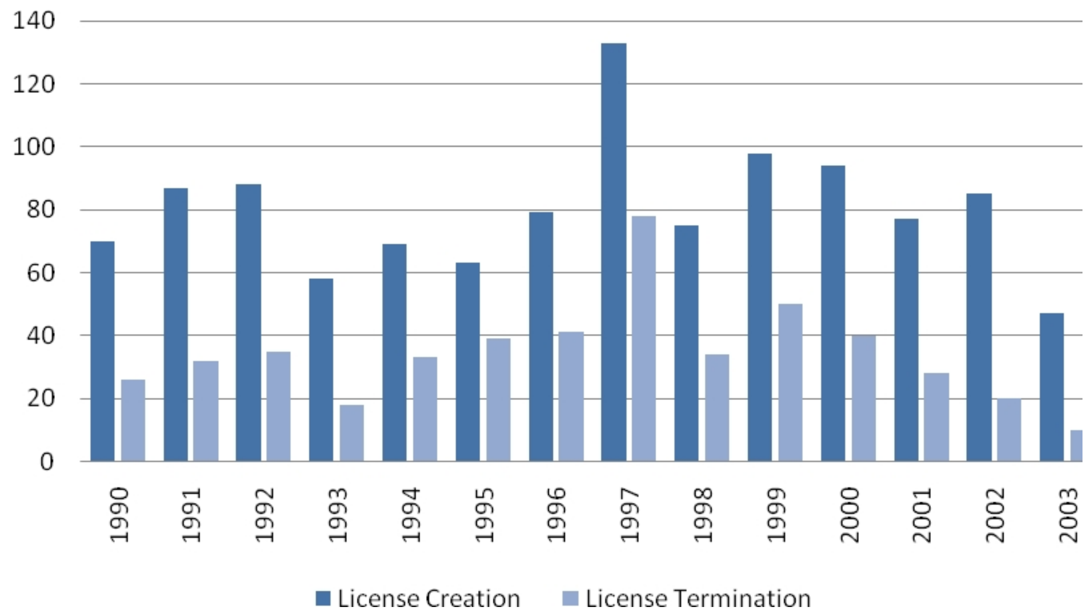


Figure 9-7: License and License Termination Event Frequency Histogram



9.3.3 Description

The dataset entails described in the following section only contains and describes data that has been used in this research. Additional data that was not used in the study can be found in the created database.

Variable	FLG_INV2USO
Model used	INV2USO
Source	Calculated from Max Planck database
Description	Dataset filter for testing hypothesis relating invention to spinout. The filter ignores patents granted to the USPTO and inventions that are disclosed outside the time frame from 1990 to 2003. Firm formation (spinout) is defined as occurring in a given year, if the invention was licensed to a for-profit firm that

did not exist as a legal entity in the previous year. If the patent is licensed to an established firm, this is defined as licensing. If a spinout that is already established comes to get another license form the university in a later year, this occurrence will be defined as licensing to an established company. Only patents that are licensed in the year of formation will be considered as leading to firm formation.

Time n/A

Variable FLG_INV2LIC

Model used INV2LIC

Source Calculated from Max Planck database

Description Dataset filter for testing hypothesis relating invention to license. The filter ignores patents granted to the USPTO and inventions that are disclosed outside the time frame from 1990 to 2003. Further, any invention that has been licensed to an established firm (but not to a spinout) is defined as licensing event. It should be noted that every invention can be involved in multiple commercialization activities e.g. one patent can be licensed to multiple parties.

Time n/A

Variable FLG_LIC2LICTERM

Model used LIC2LICTERM

Source Calculated from Max Planck database

Description Dataset filter for testing hypothesis relating invention to license termination. The filter ignores patents granted to the USPTO and inventions that are disclosed outside the time frame from 1990 to 2003. Licensing termination occurs if the licensee decides to terminate the license agreement either by not paying licensing fees or formally cancelling the contract.

Variable	FLG_USO2TERM
Model used	USO2TERM
Source	Calculated from Max Planck database
Description	Dataset filter for testing hypothesis relating invention to spinout failure. Spinout failure event is defined if a spinout ceases to exist on any given day. The date of occurrence is recorded by Max Planck and equates to the date the company was deregistered in the commercial registry.
Time	n/A

Variable	TIME_USO
Model used	INV2USO
Source	Calculated from Max Planck database
Description	Time in days from invention disclosure to spinout formation. Both dates are provided in the Max Planck database.
Time	n/A

Variable	TIME_L

Model used	INV2LIC
Source	Calculated from Max Planck database
Description	Time in days from invention disclosure to spinout formation. Both dates are provided in the Max Planck database.

Variable	TIME_LT
Model used	LIC2LICTERM
Source	Calculated from Max Planck database
Description	Time in days from licensing initiation to licensing termination. Both dates are provided in the Max Planck database.
Time	n/A

Variable	TIME_UT
Model used	USO2USOTERM
Source	Calculated from Max Planck database
Description	Time in days from spinout formation until spinout termination. Both dates are provided in the Max Planck database.
Time	n/A

Variable	DUMMY_MEDICAL, DUMMY_ELEC, DUMMY_BIOPHARM, DUMMY_MECH, DUMMY_CHEM
Model used	INV2USO, INV2LIC, LIC2LICTERM, USO2USOTERM

Source Max Planck database, and own classification

Description The industry control variable needs to control cross industry differences. The problem from the data collection perspective arises since data variables are collected from different sources which can have different industry classifications. Therefore an overreaching classification needs to be chosen that can function as a common denominator. A similar classification was previously used by Shane (2001b) to classify industries. I have therefore classified the inventions into following subgroups

- Mechanical
- Chemical
- Bio/ Pharmaceuticals
- Electrical
- Medical

This was done for following reasons:

1. The Max Planck database contained their own classification which could be easily slotted into these 5 classifications.
2. Market uncertainty variables are calculated from stock index prices which explicitly exist for the previously mentioned industry groups
3. Industry variables such as employees per company or investment figures could be gathered for the previously mentioned industry groups

The process for classifying the data was done in following way. It should be noted that the classification existing in the Max Planck database was only ca. 40% classified. Therefore the first step was to use the existing Max Planck classifications. For inventions that did not have a Max Planck classification the inventions needed to be classified manually. Since each invention contained the International Patent Classification (IPC) this code was used to fit the inventions into industries. The patent offices contain a concordance table between the IPC codes and the Standard Industrial Code (SIC) which classifications used in this study can be slotted into. Still the concordance table does not comprehensively cover all IPC codes. The remaining ones were either classified using common sense and/ or with help of Max Planck technology transfer officers.

Time	invariant

Variable	DUMMY_95_00
Model used	INV2USO, INV2LIC, LIC2LICTERM
Source	Calculated from Max Planck database
Description	Defines whether invention is disclosed between 1995 and 2000
Time	Invariant

Variable	NUM_CLAIMS
Model used	INV2USO, INV2LIC, LIC2LICTERM
Source	Patent Database
Description	Number of patent claims
Time	Invariant

Variable	IPC_NUM

Model used INV2USO, INV2LIC, LIC2LICTERM

Source Patent Database

Description Number of International Patent Classification codes

Time Invariant

Variable TECH_AGE

Model used INV2USO, INV2LIC, LIC2LICTERM

Source Patent Database

Description Each patent is classified into one or multiple IPC codes by the patent office. The date of the first patent issued in a 7 digit IPC classification is defined as the first IPC classification date for the IPC class. Technology Age is therefore defined as the age in days between the first IPC classification date and the invention disclosure date. If multiple IPC classifications dates exist for a patent, the earliest is considered.

Time Invariant

Variable MU10_INV, MU10_INV_SQ

Model used INV2USO, INV2LIC

Source Calculated from DataStream database

Description The volatilities for each invention were calculated by computing the standard deviation of the industry clusters' daily stock returns. Since the invention disclosure dates were different across inventions the market volatilities for each invention needed to be calculated separately.

As previously mentioned the volatilities needed to be industry specific covering the 5 industries chosen as controls for the analysis. For this reason I have used the FTSE Eurotop300 Indexes that follow the stock prices of these 5 technology clusters for public European companies since 1987 and calculated the volatilities of the stock composite indexes using daily data obtained from DataStream. The formula used for calculation is:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

Where x_i is the return at time i, x bar the mean return and N the number of returns. To calculate realized volatility the history of 1 year worth of data was considered. It should be noted that different time window lengths (e.g. 0.5 to 2 years) were used to calculate volatility and all produced consistent results.

Time	variant

Variable	MU10_LIC
Model used	LIC2LICTERM
Source	Calculated from DataStream database
Description	Same as MU10_INV just that the date of calculation is not invention disclosure date but licensing date.
Time	Variant

Variable	MU10_USO, MU10_USO_SQ
Model used	USO2USOTERM

Source Calculated from DataStream database

Description Same as MU10_INV just that the date of calculation is not invention disclosure date but spinout creation date.

Time Variant

Variable TU_AGG_INV

Model used INV2USO, INV2LIC

Source Patent Database

Description The patent specific technological uncertainty (TU) for each patent is measured as the average age of the cited patents (PCj) and cited non patent literature (NPLi), where j is the number of the cited patents and i is the number of cited non patent literature entries. For the reference date to calculate the average age of patents the invention disclosure date is used.

$$TU = \frac{\frac{\sum_{j}^{m} PC_j}{m} + \frac{\sum_{i}^{n} NPL_i}{n}}{2}$$

The average age of cited patents and cited non patent literature is calculated as follows. Each patent has contains none or more patent citations and non patent literature citations e.g. journals. For each of these citations the date of publication needs to be gathered. Once collected the difference between invention disclosure date and average age of patent citations or non patent literature citations is calculated.

Time Invariant

Variable TU_AGG_LIC

Model used LIC2LICTERM

Source Patent Database

Description Same as TU_AGG_INV just that instead of invention disclosure date, the licensing date is used.

Time Invariant

Variable TC_MULTI_INV

Model used INV2LIC

Source Patent Database

Description TC_{it} is the patent concentration of rivals in patent subclass i in year t indicated by the sum of patent shares PS_{ikt} for companies k=1 to n. We define patent share (PS_{ikt}) as the number of patents (P_{ikt}) in a subclass i company k has issued in a given year t divided by the total number of patents (TP_{it}) issued in this sub-class i.

$$TC_{it} = \sum_{k=1}^{n} PS_{ikt}{}^{2}$$

$$PS_{ikt} = \frac{P_{ikt}}{TP_{it}}$$

Time Variant

Variable NUM_TOTAL_REF

Model used INV2LIC, LIC2LICTERM

Source Patent Database

Description Sum of journal, patent and total references a patent cites.

Time Invariant

Variable INV_PROJECT

Model used INV2LIC, LIC2LICTERM

Source Max Planck database

Description Defines if the invention was a project invention

Time Invariant

Variable INV_PARTNER

Model used INV2LIC, LIC2LICTERM

Source Max Planck database

Description Defines if the invention was a partnered invention

Time Invariant

Variable NUM_PREV_INV

Model used INV2LIC, LIC2LICTERM

Source Max Planck database

Description Number of previous inventions an institute has disclosed at time of invention disclosure

Time	Invariant

Variable	NUM_PREV_LIC
Model used	INV2LIC, LIC2LICTERM
Source	Max Planck database
Description	Number of previous licenses the licensee has contracted with MPG at time of invention disclosure
Time	Invariant

Variable	NUM_PREV_TTO
Model used	INV2LIC, LIC2LICTERM
Source	Max Planck database
Description	Number of previous inventions a technology transfer officer has disclosed at time of invention disclosure
Time	n/A

Variable	FLG_SUPP_CONC
Model used	USO2USOTERM
Source	Max Planck database
Description	Defines if TTO gives conceptual support to founders of spinout
Time	Invariant

Variable	FLG_SUPP_BUSP
Model used	USO2USOTERM
Source	Max Planck database
Description	Defines if TTO gives founders business planning support
Time	Invariant

Variable	FLG_SUPP_FINP
Model used	USO2USOTERM
Source	Max Planck database
Description	Defines if TTO gives financial planning support to spinout founders
Time	Invariant

Variable	FLG_SUPP_LICC
Model used	USO2USOTERM
Source	Max Planck database
Description	Defines if TTO gives licensing support to spinout founders
Time	Invariant

Variable	FLG_SUPP_EQTY
Model used	USO2USOTERM

Source Max Planck database

Description Defines if TTO takes equity holding in spinout

Time Invariant

Variable FLG_FINANCING

Model used USO2USOTERM

Source Max Planck database

Description Defines if spinout has received external financing like e.g. venture capital

Time Invariant

Variable COOP_UNI

Model used USO2USOTERM

Source Max Planck database

Description Defines if spinout is founded with other university cooperation

Time Invariant

Variable COOP_INDUSTRY

Model used USO2USOTERM

Source Max Planck database

Description Defines if spinout is founded with industry cooperation

Time Invariant

Variable COOP_MPG

Model used USO2USOTERM

Source Max Planck database

Description Defines if spinout is founded in cooperation with another MPS institute

Time Invariant

Variable REV_PER_COMP

Model used USO2USOTERM

Source Calculated from Statistisches Bundesamt database (www.destatis.de)

Description Data is based on German company data. Average revenue per company (RC_{ij}) was calculated as the total revenue for industry i in year j (R_{ij}) divided by number of companies in industry i and year j (C_{ij})

$$RC_{ij} = \frac{R_{ij}}{C_{ij}}$$

Time Variant

Variable EMP_PER_COMP

Model used USO2USOTERM

Source Calculated from Statistisches Bundesamt database (www.destatis.de)

Description Data is based on German company data. Average employees per company (EC_{ij}) was calculated as the total employees in industry i in year j (E_{ij}) divided by number of companies in industry i and year j (C_{ij})

$$EC_{ij} = \frac{E_{ij}}{C_{ij}}$$

Time Variant

Variable INV_PER_COMP

Model used USO2USOTERM

Source Calculated from Statistisches Bundesamt database (www.destatis.de)

Description Data is based on German company data. Average R&D investment per company (RDC_{ij}) was calculated as the total R&D investment in industry i in year j (RD_{ij}) divided by number of companies in industry i and year j (C_{ij})

$$RDC_{ij} = \frac{RD_{ij}}{C_{ij}}$$

Time Variant

Variable VC_IND_REV

Model used USO2USOTERM

Source Venture Economics database

Description Data is based on venture capital investment in Germany. Total venture capital revenue in one of the specified industry sectors i in year j.

Time Variant

9.4 Statistical Results

9.4.1 Invention to spinout (INV2USO)

Table 9-8: Model 1 Test of Model Coefficients (INV2USO)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1246.957	42.213	5	.000	43.411	5	.000	43.411	5	.000

Table 9-9: Model 1 Variables in the Equation (INV2USO)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.148	.837	.031	1	.859	.862
DUMMY_CHEM	.488	.521	.875	1	.350	1.628
DUMMY_BIOPHARM	1.645	.464	12.584	1	.000	5.183
DUMMY_MED	1.042	.570	3.337	1	.068	2.834
DUMMY_95_00	.449	.209	4.626	1	.031	1.566

Table 9-10: Model 2 Test of Model Coefficients (INV2USO)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1223.184	74.089	11	.000	23.773	6	.001	23.773	6	.001

Table 9-11: Model 2 Variables in the Equation (INV2USO)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.029	.851	.001	1	.973	.972
DUMMY_CHEM	.614	.866	.503	1	.478	1.848
DUMMY_BIOPHARM	.748	.966	.599	1	.439	2.112
DUMMY_MED	1.168	.919	1.615	1	.204	3.215
DUMMY_95_00	.485	.216	5.050	1	.025	1.624
NUM_CLAIMS	.005	.002	5.796	1	.016	1.005
IPC_NUM	.003	.037	.009	1	.926	1.003
TECH_AGE	-.034	.010	12.072	1	.001	.966
T_EMP_PER_COMP	.004	.006	.502	1	.479	1.004
T_INV_PER_COMP_1000	-.160	.135	1.408	1	.235	.852
T_VC_IND_REV	.003	.001	8.814	1	.003	1.003

Table 9-12: Model 3 Test of Model Coefficients (INV2USO)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1193.005	90.006	14	.000	30.179	3	.000	30.179	3	.000

Table 9-13: Model 3 Variables in the Equation (INV2USO)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	1.776	1.183	2.256	1	.133	5.907
DUMMY_CHEM	2.031	1.288	2.486	1	.115	7.618
DUMMY_BIOPHARM	1.972	1.388	2.019	1	.155	7.185
DUMMY_MED	3.648	1.276	8.167	1	.004	38.381
DUMMY_95_00	.653	.221	8.697	1	.003	1.921
NUM_CLAIMS	.005	.002	5.513	1	.019	1.005
IPC_NUM	.003	.035	.007	1	.934	1.003
TECH_AGE	-.033	.010	11.148	1	.001	.967
T_EMP_PER_COMP	.009	.006	1.996	1	.158	1.009
T_INV_PER_COMP_1000	-.210	.145	2.102	1	.147	.810
T_VC_IND_REV	.002	.001	3.711	1	.054	1.002
T_MU_INV	-22.803	9.181	6.169	1	.013	.000
T_MU_INV_SQ	59.978	19.223	9.736	1	.002	1.1E+26
TU_AGG_1000_INV	.451	.142	10.123	1	.001	1.570

Table 9-14: Model of Nonlinear Technological Uncertainty (INV2USO)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	1,783	1,181	2,277	1	,131	5,946
DUMMY_CHEM	2,027	1,288	2,476	1	,116	7,594
DUMMY_BIOPHARM	1,984	1,388	2,042	1	,153	7,272
DUMMY_MED	3,677	1,275	8,311	1	,004	39,518
DUMMY_95_00	,667	,222	9,024	1	,003	1,948
NUM_CLAIMS	,005	,002	5,680	1	,017	1,005
IPC_NUM	,003	,035	,006	1	,939	1,003
TECH_AGE	-,033	,010	11,176	1	,001	,967
T_EMP_PER_COMP	,009	,006	2,014	1	,156	1,009
T_INV_PER_COMP_1000	-,210	,145	2,107	1	,147	,810
T_VC_IND_REV	,002	,001	3,759	1	,053	1,002
T_MU_INV	-22,977	9,181	6,263	1	,012	,000
T_MU_INV_SQ	60,469	19,229	9,889	1	,002	1.8E+26
TU	,624	,224	7,763	1	,005	1,866
TU_SQ	,053	,047	1,232	1	,267	1,054

9.4.2 Invention to spinout interaction effects (INV2USO)

For interaction effects I only report the last valid model and not individual model steps since they are identical to the model steps reported in Chapter 9.4.1. Further only significant relationships are reported.

Table 9-15: Test of Model Coefficients (INV2USO, Interaction of MU_INV)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1189.975	96.243	16	.000	100.393	16	.000	100.393	16	.000

Table 9-16: Variables in the Equation (INV2USO, Interaction of MU_INV and VC_IND_REV)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	1.789	1.201	2.220	1	.136	5.983
DUMMY_CHEM	2.127	1.305	2.656	1	.103	8.393
DUMMY_BIOPHARM	2.094	1.400	2.236	1	.135	8.119
DUMMY_MED	3.510	1.287	7.438	1	.006	33.448
DUMMY_95_00	.578	.226	6.528	1	.011	1.782
NUM_CLAIMS	.005	.002	4.749	1	.029	1.005
IPC_NUM	.005	.036	.022	1	.881	1.005
TECH_AGE	-.034	.010	11.655	1	.001	.966
T_EMP_PER_COMP	.008	.006	1.624	1	.203	1.008
T_INV_PER_COMP_1000	-.185	.144	1.662	1	.197	.831
T_VC_IND_REV	.047	.024	3.786	1	.052	1.048
TU_AGG_1000_INV	.435	.141	9.451	1	.002	1.544
T_MU_INV	-13.308	11.007	1.462	1	.227	.000
T_MU_INV_SQ	37.623	24.199	2.417	1	.120	2.18 E+26
T_MU_INV*T_VC_IND_REV	-.378	.204	3.425	1	.064	.685
T_MU_INV_SQ*T_VC_IND_REV	.779	.428	3.317	1	.069	2.179

9.4.3 Spinout to spinout termination (USO2USOTERM)

Table 9-17: Model 1 Test of Model Coefficients (USO2USOTERM)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
202.367	4.931	4	.294	6.733	4	.151	6.733	4	.151

Table 9-18: Model 1 Variables in the Equation (USO2USOTERM)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.825	1.134	.529	1	.467	.438
DUMMY_CHEM	-1.331	1.120	1.411	1	.235	.264
DUMMY_BIOPHARM	.220	.550	.160	1	.689	1.246
DUMMY_MED	-12.193	423.718	.001	1	.977	.000

Table 9-19: Model 2 Test of Model Coefficients (USO2USOTERM)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
144.752	60.424	17	.000	57.616	13	.000	57.616	13	.000

Table 9-20: Model 2 Variables in the Equation (USO2USOTERM)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.178	1.402	.016	1	.899	.837
DUMMY_CHEM	2.530	3.213	.620	1	.431	12.548
DUMMY_BIOPHARM	5.771	4.610	1.567	1	.211	320.843
DUMMY_MED	-17.654	657.830	.001	1	.979	.000
FLG_SUPP_CONC	.821	.613	1.792	1	.181	2.272
FLG_SUPP_BUSP	-.641	.888	.521	1	.470	.527
FLG_SUPP_FINP	.288	.890	.105	1	.746	1.334
FLG_SUPP_LICC	-.766	.873	.770	1	.380	.465
FLG_SUPP_EQTY	1.152	1.201	.920	1	.338	3.164
FLG_FINANCING	-2.090	1.024	4.167	1	.041	.124
COOP_UNI	-3.085	1.289	5.730	1	.017	.046
COOP_INDUSTRY	-2.595	1.101	5.554	1	.018	.075
COOP_MPG	-.199	.655	.092	1	.762	.820
T_EMP_PER_COMP	-.037	.024	2.332	1	.127	.963
T_INV_PER_COMP_1000	.981	.440	4.985	1	.026	2.668
T_REV_PER_COMP	-.005	.015	.111	1	.739	.995
T_VC_IND_REV	.006	.003	6.041	1	.014	1.006

Table 9-21: Model 3 Test of Model Coefficients (USO2USOTERM)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
137.031	64.611	19	.000	7.721	2	.021	7.721	2	.021

Table 9-22: Model 3 Variables in the Equation (USO2USOTERM)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	.163	1.706	.009	1	.924	1.177
DUMMY_CHEM	2.142	3.443	.387	1	.534	8.514
DUMMY_BIOPHARM	5.125	4.507	1.293	1	.256	168.128
DUMMY_MED	-16.682	679.718	.001	1	.980	.000
FLG_SUPP_CONC	.786	.623	1.592	1	.207	2.195
FLG_SUPP_BUSP	-.433	.919	.222	1	.638	.649
FLG_SUPP_FINP	-.044	.894	.002	1	.960	.957
FLG_SUPP_LICC	-.561	.902	.386	1	.534	.571
FLG_SUPP_EQTY	1.872	1.204	2.415	1	.120	6.500
FLG_FINANCING	-2.924	1.009	8.394	1	.004	.054
COOP_UNI	-3.447	1.379	6.245	1	.012	.032
COOP_INDUSTRY	-3.091	1.150	7.227	1	.007	.045
COOP_MPG	-.301	.685	.193	1	.660	.740
T_EMP_PER_COMP	-.032	.024	1.835	1	.175	.968
T_INV_PER_COMP_1000	1.021	.455	5.035	1	.025	2.776
T_REV_PER_COMP	-.005	.014	.130	1	.718	.995
T_VC_IND_REV	.008	.003	7.166	1	.007	1.008
T_MU_USO	-49.147	17.810	7.615	1	.006	.000
T_MU_USO_SQ	111.545	41.168	7.341	1	.007	2.77E+048

9.4.4 Spinout to spinout termination interaction effects (USO2USOTERM)

For interaction effects I only report the last valid model and not individual model steps since they are identical to the model steps reported in Chapter 9.4.1. Further only significant relationships are reported.

Table 9-23: Test of Model Coefficients (USO2USOTERM, Interaction of MU_INV and FLG_SUPP_BSP)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
127.181	67.324	21	.000	81.920	21	.000	81.920	21	.000

Table 9-24: Variables in the Equation (INV2USO, Interaction of MU_INV and FLG_SUPP_BSP)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-1.132	2.225	.259	1	.611	.322
DUMMY_CHEM	5.278	4.293	1.511	1	.219	195.896
DUMMY_BIOPHARM	8.934	6.211	2.069	1	.150	7584.919
DUMMY_MED	-20.270	657.225	.001	1	.975	.000
FLG_SUPP_CONC	.858	.723	1.406	1	.236	2.358
FLG_SUPP_BUSP	-42.615	23.292	3.348	1	.067	.000
FLG_SUPP_FINP	1.508	1.195	1.592	1	.207	4.518
FLG_SUPP_LICC	-.331	.995	.111	1	.739	.718
FLG_SUPP_EQTY	1.490	1.695	.773	1	.379	4.438
FLG_FINANCING	-4.607	1.596	8.333	1	.004	.010
COOP_UNI	-4.503	1.528	8.685	1	.003	.011
COOP_INDUSTRY	-2.679	1.382	3.758	1	.053	.069
COOP_MPG	.026	.785	.001	1	.973	1.026
T_EMP_PER_COMP	-.054	.032	2.828	1	.093	.948
T_INV_PER_COMP_1000	1.020	.477	4.566	1	.033	2.772
T_REV_PER_COMP	.000	.015	.000	1	.998	1.000
T_VC_IND_REV	.008	.003	4.771	1	.029	1.008
T_MU_USO	39.132	42.318	.855	1	.355	9.88E+16
T_MU_USO_SQ	-72.618	111.450	.425	1	.515	.000
T_MU_USO*FLG_SUPP_BUSP	541.293	285.372	3.598	1	.058	1.2E+235
T_MU_USO_SQ*FLG_SUPP_BUSP	-1671.147	852.599	3.842	1	.050	.000

Table 9-25: Test of Model Coefficients (USO2USOTERM, Interaction of MU_INV and FLG_SUPP_BSP)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
121.989	70.753	21	.000	87.112	21	.000	87.112	21	.000

Table 9-26: Variables in the Equation (INV2USO, Interaction of MU_INV and FLG_SUPP_BSP)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-5.954	2.475	5.785	1	.016	.003
DUMMY_CHEM	9.995	5.468	3.342	1	.068	21923.354
DUMMY_BIOPHARM	16.059	7.576	4.494	1	.034	9427915
DUMMY_MED	-29.971	720.644	.002	1	.967	.000
FLG_SUPP_CONC	.673	.749	.806	1	.369	1.960
FLG_SUPP_BUSP	-.148	1.039	.020	1	.887	.862
FLG_SUPP_FINP	-.638	1.034	.380	1	.537	.529
FLG_SUPP_LICC	-1.233	1.066	1.338	1	.247	.291
FLG_SUPP_EQTY	3.298	1.685	3.830	1	.050	27.051
FLG_FINANCING	-3.354	1.127	8.852	1	.003	.035
COOP_UNI	-5.244	1.640	10.231	1	.001	.005
COOP_INDUSTRY	-4.681	1.711	7.481	1	.006	.009
COOP_MPG	.492	.804	.374	1	.541	1.635
T_EMP_PER_COMP	-.102	.038	7.267	1	.007	.903
T_INV_PER_COMP_1000	1.294	.481	7.227	1	.007	3.647
T_REV_PER_COMP	.006	.015	.179	1	.672	1.006
T_VC_IND_REV	.220	.076	8.383	1	.004	1.246
T_MU_USO	233.797	72.639	10.359	1	.001	3.44E+101
T_MU_USO_SQ	-593	186.552	10.128	1	.001	.000
T_MU_USO*T_VC_IND_REV	-2.097	.811	6.682	1	.010	.123
T_MU_USO_SQ*T_VC_IND_REV	5.217	2.215	5.546	1	.019	184.300

9.4.5 Invention to license (INV2LIC)

Table 9-27: Model 1 Test of Model Coefficients (INV2LIC)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4930.933	31.283	4	.000	35.350	4	.000	35.350	4	.000

Table 9-28: Model 1 Variables in the Equation (INV2LIC)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.055	.337	.027	1	.869	.946
DUMMY_CHEM	.668	.200	11.125	1	.001	1.951
DUMMY_BIOPHARM	.850	.189	20.193	1	.000	2.339
DUMMY_MED	.925	.226	16.714	1	.000	2.522

Table 9-29: Model 2 Test of Model Coefficients (INV2LIC)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4776.192	213.860	13	.000	154.741	9	.000	154.741	9	.000

Table 9-30: Model 2 Variables in the Equation (INV2LIC)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.153	.341	.202	1	.653	.858
DUMMY_CHEM	.292	.206	2.015	1	.156	1.339
DUMMY_BIOPHARM	.437	.199	4.809	1	.028	1.548
DUMMY_MED	.533	.231	5.308	1	.021	1.704
NUM_TOTAL_REF	.023	.012	3.511	1	.061	1.024
NUM_CLAIMS	.003	.002	1.779	1	.182	1.003
IPC_NUM	-.007	.018	.136	1	.712	.993
TECH_AGE	-.006	.005	1.684	1	.194	.994
INV_PROJECT	.032	.189	.028	1	.867	1.032
INV_PARTNER	.999	.109	84.146	1	.000	2.716
NUM_PREV_INV_1000	.400	2.491	.026	1	.873	1.491
NUM_PREV_LIC	.008	.003	8.325	1	.004	1.008
NUM_PREV_TTO	.003	.002	1.645	1	.200	1.003

Table 9-31: Model 3 Test of Model Coefficients (INV2LIC)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4762.277	224.786	17	.000	13.916	4	.008	13.916	4	.008

Table 9-32: Model 3 Variables in the Equation (INV2LIC)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.280	.357	.614	1	.433	.756
DUMMY_CHEM	.192	.240	.637	1	.425	1.211
DUMMY_BIOPHARM	.148	.242	.371	1	.542	1.159
DUMMY_MED	.239	.262	.836	1	.361	1.270
NUM_TOTAL_REF	.026	.013	3.888	1	.049	1.026
NUM_CLAIMS	.002	.002	1.085	1	.298	1.002
IPC_NUM	-.005	.018	.083	1	.774	.995
TECH_AGE	-.005	.005	1.331	1	.249	.995
INV_PROJECT	-.017	.191	.008	1	.928	.983
INV_PARTNER	.999	.109	84.001	1	.000	2.715
NUM_PREV_INV_1000	.203	2.627	.006	1	.938	1.225
NUM_PREV_LIC	.007	.003	6.009	1	.014	1.007
NUM_PREV_TTO	.002	.002	.768	1	.381	1.002
T_MU_INV	12.361	4.916	6.323	1	.012	233626
T_MU_INV_SQ	-27.947	13.104	4.549	1	.033	.000
TU_AGG_1000_INV	.054	.049	1.220	1	.269	1.056
TC_MULTI_INV_LN	-.196	.087	5.063	1	.024	.822

Table 9-33: Model of Nonlinear Technological Uncertainty (INV2LIC)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-,280	,357	,613	1	,434	,756
DUMMY_CHEM	,187	,240	,604	1	,437	1,205
DUMMY_BIOPHARM	,143	,242	,347	1	,556	1,154
DUMMY_MED	,239	,262	,832	1	,362	1,270
NUM_TOTAL_REF	,028	,013	4,291	1	,038	1,028
NUM_CLAIMS	,002	,002	1,083	1	,298	1,002
IPC_NUM	-,006	,018	,094	1	,759	,994
TECH_AGE	-,005	,005	1,330	1	,249	,995
INV_PROJECT	-,014	,191	,005	1	,941	,986
INV_PARTNER	,998	,109	83,870	1	,000	2,714
NUM_PREV_INV_1000	,145	2,632	,003	1	,956	1,157
NUM_PREV_LIC	,007	,003	6,151	1	,013	1,007
NUM_PREV_TTO	,002	,002	,732	1	,392	1,002
T_MU_INV	12,377	4,917	6,336	1	,012	237398
T_MU_INV_SQ	-27,921	13,109	4,536	1	,033	,000
TU	,114	,106	1,152	1	,283	1,120
TU_SQ	,013	,020	,414	1	,520	1,013
TC_MULTI_INV_LN	-,197	,087	5,145	1	,023	,821

9.4.6 Invention to license interaction effects (INV2LIC)

For interaction effects I only report the last valid model and not individual model steps since they are identical to the model steps reported in Chapter 9.4.5. Further only significant relationships are reported.

Table 9-34: Test of Model Coefficients (INV2LIC, MU_INV and NUM_CLAIMS)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4753.821	230.806	19	.000	212.462	19	.000	212.462	19	.000

Table 9-35: Variables in the Equation (INV2LIC, MU_INV and NUM_CLAIMS)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.301	.357	.709	1	.400	.740
DUMMY_CHEM	.159	.240	.441	1	.507	1.173
DUMMY_BIOPHARM	.120	.242	.245	1	.621	1.127
DUMMY_MED	.206	.262	.619	1	.431	1.229
NUM_TOTAL_REF	.024	.013	3.531	1	.060	1.025
NUM_CLAIMS	.046	.019	6.001	1	.014	1.047
IPC_NUM	.000	.018	.000	1	.988	1.000
TECH_AGE	-.006	.005	1.470	1	.225	.994
INV_PROJECT	-.014	.191	.005	1	.943	.986
INV_PARTNER	1.003	.109	84.803	1	.000	2.726
NUM_PREV_INV_1000	-.137	2.682	.003	1	.959	.872
NUM_PREV_LIC	.007	.003	6.202	1	.013	1.007
NUM_PREV_TTO	.002	.002	.870	1	.351	1.002
T_MU_INV	23.386	6.858	11.628	1	.001	1.43E+10
T_MU_INV_SQ	-62.660	18.915	10.974	1	.001	.000
TU_AGG_1000_INV	.052	.049	1.099	1	.295	1.053
TC_MULTI_INV_LN	-.202	.087	5.352	1	.021	.817
T_MU_INV*NUM_CLAIMS	-.598	.227	6.962	1	.008	.550
T_MU_INV_SQ*NUM_CLAIMS	1.879	.632	8.826	1	.003	6.544

Table 9-36: Test of Model Coefficients (INV2LIC, Interaction of TU_AGG_1000_INV and INV_PARTNER)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4751.934	233.630	18	.000	214.349	18	.000	214.349	18	.000

Table 9-37: Variables in the Equation (INV2LIC, Interaction of TU_AGG_1000_INV and INV_PARTNER)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.250	.357	.491	1	.483	.779
DUMMY_CHEM	.187	.240	.605	1	.437	1.206
DUMMY_BIOPHARM	.138	.241	.329	1	.566	1.148
DUMMY_MED	.226	.261	.746	1	.388	1.253
NUM_TOTAL_REF	.026	.013	4.142	1	.042	1.027
NUM_CLAIMS	.003	.002	1.348	1	.246	1.003
IPC_NUM	-.008	.018	.204	1	.652	.992
TECH_AGE	-.005	.005	1.349	1	.246	.995
INV_PROJECT	-.015	.190	.006	1	.938	.985
INV_PARTNER	.680	.147	21.473	1	.000	1.975
NUM_PREV_INV_1000	-.230	2.725	.007	1	.933	.795
NUM_PREV_LIC	.007	.003	6.043	1	.014	1.007
NUM_PREV_TTO	.002	.002	1.005	1	.316	1.002
T_MU_INV	11.933	4.908	5.911	1	.015	152162
T_MU_INV_SQ	-26.84	13.072	4.219	1	.040	.000
TU_AGG_1000_INV	.246	.085	8.376	1	.004	1.279
TC_MULTI_INV_LN	-.187	.086	4.747	1	.029	.829
TU_AGG_1000_INV*INV_PARTNER	-.313	.100	9.738	1	.002	.731

Table 9-38: Test of Model Coefficients (INV2LIC, Interaction of TU_AGG_1000_INV and NUM_PREV_INV)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4759.227	227.774	18	.000	207.056	18	.000	207.056	18	.000

Table 9-39: Variables in the Equation (INV2LIC, Interaction of TU_AGG_1000_INV)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.295	.357	.681	1	.409	.745
DUMMY_CHEM	.194	.240	.654	1	.419	1.215
DUMMY_BIOPHARM	.144	.242	.355	1	.552	1.155
DUMMY_MED	.238	.262	.830	1	.362	1.269
NUM_TOTAL_REF	.026	.013	3.854	1	.050	1.026
NUM_CLAIMS	.003	.002	1.340	1	.247	1.003
IPC_NUM	-.009	.018	.235	1	.628	.991
TECH_AGE	-.005	.005	1.430	1	.232	.995
INV_PROJECT	-.020	.191	.011	1	.916	.980
INV_PARTNER	.995	.109	83.176	1	.000	2.704
NUM_PREV_INV_1000	-2.288	3.003	.581	1	.446	.101
NUM_PREV_LIC	.007	.003	6.645	1	.010	1.007
NUM_PREV_TTO	.002	.002	.961	1	.327	1.002
T_MU_INV	12.265	4.918	6.218	1	.013	212039
T_MU_INV_SQ	-27.49	13.099	4.405	1	.036	.000
TU_AGG_1000_INV	.137	.070	3.799	1	.051	1.147
TC_MULTI_INV_LN	-.197	.087	5.138	1	.023	.821
TU_AGG_1000_INV*NUM_PREV_INV_1000	-1.858	1.030	3.258	1	.071	.156

Table 9-40: Test of Model Coefficients (INV2LIC, Interaction of TC_MULTI_INV_LN and TECH_AGE)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4756.211	230.193	18	.000	210.072	18	.000	210.072	18	.000

Table 9-41: Variables in the Equation (INV2LIC, Interaction of TC_MULTI_INV_LN and TECH_AGE)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.297	.357	.692	1	.406	.743
DUMMY_CHEM	.143	.241	.350	1	.554	1.153
DUMMY_BIOPHARM	.125	.243	.265	1	.607	1.133
DUMMY_MED	.231	.262	.777	1	.378	1.260
NUM_TOTAL_REF	.027	.013	4.281	1	.039	1.027
NUM_CLAIMS	.002	.002	.957	1	.328	1.002
IPC_NUM	-.005	.018	.075	1	.784	.995
TECH_AGE	-.047	.017	7.252	1	.007	.954
INV_PROJECT	-.017	.191	.008	1	.931	.984
INV_PARTNER	1.004	.109	84.717	1	.000	2.729
NUM_PREV_INV	.001	.003	.041	1	.839	1.001
NUM_PREV_LIC	.007	.003	6.332	1	.012	1.007
NUM_PREV_TTO	.002	.002	.757	1	.384	1.002
T_MU_INV	12.63	4.922	6.587	1	.010	306092
T_MU_INV_SQ	-28.7	13.120	4.797	1	.029	.000
TU_AGG_1000_INV	.055	.049	1.264	1	.261	1.057
TC_MULTI_INV_LN	-.455	.138	10.874	1	.001	.634
TC_MULTI_INV_LN*TECH_AGE	.016	.006	6.323	1	.012	1.016

Table 9-42: Test of Model Coefficients (INV2LIC, Interaction of TC_MULTI_INV_LN and INV_PARTNER)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4745.927	227.540	18	.000	220.356	18	.000	220.356	18	.000

Table 9-43: Variables in the Equation (INV2LIC, Interaction of TC_MULTI_INV_LN and INV_PARTNER)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.486	.361	1.811	1	.178	.615
DUMMY_CHEM	.022	.242	.008	1	.928	1.022
DUMMY_BIOPHARM	-.036	.244	.022	1	.883	.965
DUMMY_MED	.057	.264	.046	1	.830	1.058
NUM_TOTAL_REF	.029	.013	4.924	1	.026	1.029
NUM_CLAIMS	.003	.002	1.554	1	.213	1.003
IPC_NUM	-.005	.018	.070	1	.791	.995
TECH_AGE	-.005	.005	1.235	1	.267	.995
INV_PROJECT	.011	.191	.004	1	.953	1.011
INV_PARTNER	-.625	.421	2.206	1	.137	.535
NUM_PREV_INV	.000	.003	.014	1	.907	1.000
NUM_PREV_LIC	.008	.003	8.011	1	.005	1.008
NUM_PREV_TTO	.001	.002	.405	1	.525	1.001
T_MU_INV	12.74	4.902	6.761	1	.009	343448
T_MU_INV_SQ	-29.06	13.066	4.947	1	.026	.000
TU_AGG_1000_INV	.051	.049	1.086	1	.297	1.052
TC_MULTI_INV_LN	-.604	.143	17.884	1	.000	.547
TC_MULTI_INV_LN*INV_PARTNER	.666	.168	15.666	1	.000	1.946

Table 9-44: Test of Model Coefficients (INV2LIC, Interaction of TC_MULTI_INV_LN and NUM_PREV_INV)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4759.290	225.244	18	.000	206.993	18	.000	206.993	18	.000

Table 9-45: Variables in the Equation (INV2LIC, Interaction of TC_MULTI_INV_LN and NUM_PREV_INV)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.314	.358	.770	1	.380	.730
DUMMY_CHEM	.167	.241	.481	1	.488	1.182
DUMMY_BIOPHARM	.122	.243	.253	1	.615	1.130
DUMMY_MED	.216	.263	.677	1	.410	1.241
NUM_TOTAL_REF	.025	.013	3.733	1	.053	1.026
NUM_CLAIMS	.002	.002	1.239	1	.266	1.002
IPC_NUM	-.006	.018	.120	1	.729	.994
TECH_AGE	-.005	.005	1.354	1	.245	.995
INV_PROJECT	-.011	.191	.003	1	.954	.989
INV_PARTNER	1.010	.109	85.705	1	.000	2.746
NUM_PREV_INV	-.009	.006	2.392	1	.122	.991
NUM_PREV_LIC	.008	.003	7.109	1	.008	1.008
NUM_PREV_TTO	.002	.002	1.024	1	.312	1.002
T_MU_INV	12.54	4.919	6.501	1	.011	279795
T_MU_INV_SQ	-28.8	13.127	4.834	1	.028	.000
TU_AGG_1000_INV	.053	.049	1.150	1	.284	1.054
TC_MULTI_INV_LN	-.307	.109	7.862	1	.005	.736
TC_MULTI_INV_LN*NUM_PREV_INV	.003	.002	3.264	1	.071	1.003

Table 9-46: Test of Model Coefficients (INV2LIC, Interaction of TC_MULTI_INV_LN and NUM_PREV_LIC)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4758.576	225.446	18	.000	207.708	18	.000	207.708	18	.000

Table 9-47: Variables in the Equation (INV2LIC, Interaction of TC_MULTI_INV_LN and NUM_PREV_LIC)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.283	.357	.628	1	.428	.753
DUMMY_CHEM	.168	.241	.490	1	.484	1.183
DUMMY_BIOPHARM	.119	.242	.243	1	.622	1.127
DUMMY_MED	.211	.262	.646	1	.422	1.235
NUM_TOTAL_REF	.026	.013	4.042	1	.044	1.027
NUM_CLAIMS	.003	.002	1.300	1	.254	1.003
IPC_NUM	-.005	.018	.075	1	.783	.995
TECH_AGE	-.005	.005	1.281	1	.258	.995
INV_PROJECT	-.013	.191	.005	1	.944	.987
INV_PARTNER	1.023	.110	86.921	1	.000	2.781
NUM_PREV_INV	.001	.003	.267	1	.606	1.001
NUM_PREV_LIC	-.005	.007	.593	1	.441	.995
NUM_PREV_TTO	.002	.002	.761	1	.383	1.002
T_MU_INV	12.649	4.913	6.628	1	.010	311420
T_MU_INV_SQ	-29.08	13.111	4.922	1	.027	.000
TU_AGG_1000_INV	.053	.049	1.188	1	.276	1.055
TC_MULTI_INV_LN	-.304	.105	8.360	1	.004	.738
TC_MULTI_INV_LN*NUM_PREV_LIC	.004	.002	3.974	1	.046	1.004

9.4.7 License to license termination (LIC2LICTERM)

Table 9-48: Model 1 Test of Model Coefficients (LIC2LICTERM)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1540.887	22.674	5	.000	24.033	5	.000	24.033	5	.000

Table 9-49: Model 1 Variables in the Equation (LIC2LICTERM)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.583	.758	.593	1	.441	.558
DUMMY_CHEM	-.495	.338	2.149	1	.143	.610
DUMMY_BIOPHARM	-.116	.289	.160	1	.689	.891
DUMMY_MED	-.197	.362	.297	1	.586	.821
DUMMY_95_00	.895	.208	18.547	1	.000	2.446

Table 9-50: Model 2 Test of Model Coefficients (LIC2LICTERM)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1451.149	107.214	14	.000	89.738	9	.000	89.738	9	.000

Table 9-51: Model 2 Variables in the Equation (LIC2LICTERM)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.314	.785	.160	1	.689	.730
DUMMY_CHEM	-.120	.367	.107	1	.744	.887
DUMMY_BIOPHARM	.002	.315	.000	1	.996	1.002
DUMMY_MED	.065	.380	.029	1	.864	1.067
DUMMY_95_00	1.045	.250	17.510	1	.000	2.843
NUM_TOTAL_REF	.015	.023	.463	1	.496	1.016
NUM_CLAIMS	-.008	.005	2.183	1	.140	.992
IPC_NUM	-.039	.034	1.291	1	.256	.962
TECH_AGE	-.005	.007	.420	1	.517	.995
INV_PROJECT	.838	.339	6.105	1	.013	2.313
INV_PARTNER	-1.633	.207	62.013	1	.000	.195
NUM_PREV_INV	.018	.008	5.727	1	.017	1.019
NUM_PREV_LIC	-.015	.009	2.823	1	.093	.985
NUM_PREV_TTO	-.001	.004	.033	1	.855	.999

Table 9-52: Model 3 Test of Model Coefficients (LIC2LICTERM)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1433.347	119.057	17	.000	17.802	3	.000	17.802	3	.000

Table 9-53: Model 3 Variables in the Equation (LIC2LICTERM)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.236	.787	.090	1	.764	.789
DUMMY_CHEM	.201	.380	.281	1	.596	1.223
DUMMY_BIOPHARM	.104	.325	.102	1	.750	1.109
DUMMY_MED	-.057	.387	.022	1	.882	.944
DUMMY_94_03	1.229	.256	23.069	1	.000	3.419
NUM_TOTAL_REF	.035	.024	2.119	1	.145	1.035
NUM_CLAIMS	-.010	.006	3.113	1	.078	.990
IPC_NUM	-.065	.036	3.220	1	.073	.937
TECH_AGE	-.005	.007	.529	1	.467	.995
INV_PROJECT	.724	.341	4.513	1	.034	2.063
INV_PARTNER	-1.703	.211	64.914	1	.000	.182
NUM_PREV_INV	.020	.008	6.656	1	.010	1.020
NUM_PREV_LIC	-.018	.009	4.158	1	.041	.982
NUM_PREV_TTO	-.001	.004	.122	1	.727	.999
T_MU_LIC	21.710	8.347	6.765	1	.009	2.684E+09
T_MU_LIC_SQ	-56.577	25.190	5.045	1	.025	.000
TU_AGG_1000_LIC	.151	.072	4.389	1	.036	1.163

Table 9-54: Model of Nonlinear Technological Uncertainty (LIC2LICTERM)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-,250	,786	,101	1	,751	,779
DUMMY_CHEM	,144	,385	,139	1	,709	1,154
DUMMY_BIOPHARM	,083	,326	,065	1	,798	1,087
DUMMY_MED	-,095	,390	,059	1	,808	,909
DUMMY_94_03	1,204	,257	21,876	1	,000	3,333
NUM_TOTAL_REF	,037	,024	2,477	1	,115	1,038
NUM_CLAIMS	-,010	,006	3,020	1	,082	,990
IPC_NUM	-,064	,036	3,129	1	,077	,938
TECH_AGE	-,005	,007	,546	1	,460	,995
INV_PROJECT	,739	,342	4,674	1	,031	2,093
INV_PARTNER	-1,702	,212	64,706	1	,000	,182
NUM_PREV_INV	,021	,008	7,049	1	,008	1,021
NUM_PREV_LIC	-,019	,009	4,588	1	,032	,981
NUM_PREV_TTO	-,001	,004	,091	1	,763	,999
T_MU_LIC	21,642	8,310	6,782	1	,009	2.5E+09
T_MU_LIC_SQ	-56,470	25,057	5,079	1	,024	,000
TU	,315	,181	3,011	1	,083	1,370
TU_SQ	,034	,035	,992	1	,319	1,035

9.4.8 License to license termination interaction effects (LIC2LICTERM)

For interaction effects I only report the last valid model and not individual model steps. Further only significant relationships are reported.

Table 9-55: Test of Model Coefficients (LIC2LICTERM, Interaction of MU_ LIC with NUM_CLAIMS)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1429.425	119.756	19	.000	135.495	19	.000	135.495	19	.000

Table 9-56: Variables in the Equation (LIC2LICTERM, Interaction of MU_LIC with NUM_CLAIMS)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.270	.787	.118	1	.732	.763
DUMMY_CHEM	.204	.381	.285	1	.593	1.226
DUMMY_BIOPHARM	.107	.324	.110	1	.741	1.113
DUMMY_MED	-.054	.388	.020	1	.889	.947
DUMMY_94_03	1.252	.256	23.974	1	.000	3.497
NUM_TOTAL_REF	.033	.024	1.907	1	.167	1.033
NUM_CLAIMS	.037	.021	3.151	1	.076	1.038
IPC_NUM	-.066	.036	3.411	1	.065	.936
TECH_AGE	-.006	.007	.588	1	.443	.994
INV_PROJECT	.750	.342	4.809	1	.028	2.117
INV_PARTNER	-1.727	.213	65.836	1	.000	.178
NUM_PREV_INV_1000	19.627	7.823	6.294	1	.012	3.3E+08
NUM_PREV_LIC	-.018	.009	4.039	1	.044	.982
NUM_PREV_TTO	-.001	.004	.064	1	.800	.999
T_MU_LIC	31.653	10.325	9.398	1	.002	5.6E+13
T_MU_LIC_SQ	-82.963	31.723	6.839	1	.009	.000
TU_AGG_1000_LIC	.151	.071	4.459	1	.035	1.163
T_MU_LIC*NUM_CLAIMS	-.596	.281	4.506	1	.034	.551
T_MU_LIC_SQ*NUM_CLAIMS	1.492	.748	3.976	1	.046	4.446

Table 9-57: Test of Model Coefficients (LIC2LICTERM, Interaction of TU_AGG_1000_LIC with NUM_PREV_TTO)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1422.794	125.239	18	.000	142.127	18	.000	142.127	18	.000

Table 9-58: Variables in the Equation (LIC2LICTERM, Interaction of TU_AGG_1000_LIC with NUM_PREV_TTO)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.324	.785	.170	1	.680	.723
DUMMY_CHEM	.478	.385	1.539	1	.215	1.612
DUMMY_BIOPHARM	.255	.325	.615	1	.433	1.290
DUMMY_MED	.014	.386	.001	1	.970	1.014
DUMMY_94_03	1.198	.257	21.697	1	.000	3.313
NUM_TOTAL_REF	.016	.024	.436	1	.509	1.016
NUM_CLAIMS	-.010	.006	3.137	1	.077	.990
IPC_NUM	-.060	.036	2.775	1	.096	.942
TECH_AGE	-.006	.007	.742	1	.389	.994
INV_PROJECT	.740	.343	4.637	1	.031	2.095
INV_PARTNER	-1.791	.216	68.498	1	.000	.167
NUM_PREV_INV_1000	24.480	7.838	9.754	1	.002	4.28E+10
NUM_PREV_LIC	-.022	.009	6.349	1	.012	.978
NUM_PREV_TTO	-.018	.007	6.887	1	.009	.982
T_MU_LIC	20.585	8.226	6.263	1	.012	8.71E+08
T_MU_LIC_SQ	-53.78	24.775	4.712	1	.030	.000
TU_AGG_1000_LIC	.396	.105	14.108	1	.000	1.486
TU_AGG_1000_LIC*NUM_PREV_TTO	-.010	.003	11.537	1	.001	.990

Table 9-59: Test of Model Coefficients (LIC2LICTERM, Interaction of TU_AGG_1000_LIC)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1414.359	134.222	18	.000	150.562	18	.000	150.562	18	.000

Table 9-60: Variables in the Equation (LIC2LICTERM, Interaction of TU_AGG_1000_LIC with TECH_AGE)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.558	.805	.480	1	.488	.572
DUMMY_CHEM	.061	.384	.026	1	.873	1.063
DUMMY_BIOPHARM	-.016	.328	.002	1	.962	.985
DUMMY_MED	-.168	.388	.186	1	.666	.846
DUMMY_94_03	1.305	.260	25.167	1	.000	3.689
NUM_TOTAL_REF	.034	.023	2.140	1	.143	1.035
NUM_CLAIMS	-.011	.006	3.706	1	.054	.989
IPC_NUM	-.063	.036	3.030	1	.082	.939
TECH_AGE	-.027	.014	3.764	1	.052	.973
INV_PROJECT	.665	.342	3.782	1	.052	1.944
INV_PARTNER	-1.704	.212	64.541	1	.000	.182
NUM_PREV_INV_1000	22.712	8.096	7.870	1	.005	7.30E+09
NUM_PREV_LIC	-.020	.009	4.856	1	.028	.980
NUM_PREV_TTO	-.003	.004	.426	1	.514	.997
T_MU_LIC	21.321	8.270	6.647	1	.010	1.81E+09
T_MU_LIC_SQ	-55.79	24.930	5.009	1	.025	.000
TU_AGG_1000_LIC	.284	.102	7.682	1	.006	1.328
TU_AGG_1000_LIC*TECH_AGE	-.011	.006	3.542	1	.060	.989

9.4.9 Competing Risk Model between Spinout and Licensing (USOvsLIC)

The following results present the raw data used to calculate the tests between covariants for the competing risk analysis.

Table 9-61: Test of Model Coefficients (INV2USO + INV2LIC)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
5981.850	345.978	19	.000	12.670	2	.002	12.670	2	.002

Table 9-62: Variables in the Equation (INV2USO + INV2LIC)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.300	.334	.806	1	.369	.741
DUMMY_CHEM	.716	.403	3.154	1	.076	2.046
DUMMY_BIOPHARM	.366	.492	.554	1	.457	1.442
DUMMY_MED	.360	.367	.961	1	.327	1.434
DUMMY_95_00	.418	.110	14.541	1	.000	1.519
NUM_TOTAL_REF	.015	.012	1.569	1	.210	1.015
NUM_CLAIMS	.003	.002	2.586	1	.108	1.003
IPC_NUM	.002	.015	.010	1	.920	1.002
TECH_AGE	-.011	.004	6.701	1	.010	.989
INV_PROJECT	-.122	.168	.526	1	.468	.885
INV_PARTNER	.965	.097	99.503	1	.000	2.624
NUM_PREV_INV_1000	-.955	2.384	.160	1	.689	.385
NUM_PREV_LIC	.007	.003	8.456	1	.004	1.007
NUM_PREV_TTO	.004	.002	5.507	1	.019	1.004
T_EMP_PER_COMP	.002	.003	.430	1	.512	1.002
T_INV_PER_COMP_1000	-.149	.046	10.332	1	.001	.862
T_VC_IND_REV	.001	.000	4.828	1	.028	1.001
TU_AGG_1000_INV	.115	.047	5.871	1	.015	1.122
TC_MULTI_INV_LN	-.211	.081	6.868	1	.009	.810

Table 9-63: Test of Model Coefficients (INV2USO)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
1176.039	122.304	19	.000	8.178	2	.017	8.178	2	.017

Table 9-64: Variables in the Equation (INV2USO)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.112	.856	.017	1	.896	.894
DUMMY_CHEM	.112	.891	.016	1	.900	1.118
DUMMY_BIOPHARM	.218	1.044	.043	1	.835	1.243
DUMMY_MED	1.057	.921	1.317	1	.251	2.876
DUMMY_95_00	.399	.226	3.113	1	.078	1.491
NUM_TOTAL_REF	-.034	.031	1.211	1	.271	.966
NUM_CLAIMS	.005	.002	4.186	1	.041	1.005
IPC_NUM	-.007	.036	.038	1	.845	.993
TECH_AGE	-.031	.010	9.590	1	.002	.970
INV_PROJECT	.151	.286	.278	1	.598	1.163
INV_PARTNER	.852	.221	14.866	1	.000	2.343
NUM_PREV_INV_1000	-4.84	5.323	.828	1	.363	.008
NUM_PREV_LIC	.012	.006	3.476	1	.062	1.012
NUM_PREV_TTO	.009	.003	7.382	1	.007	1.009
T_EMP_PER_COMP	.006	.006	1.172	1	.279	1.006
T_INV_PER_COMP_1000	-.221	.134	2.705	1	.100	.802
T_VC_IND_REV	.001	.001	1.666	1	.197	1.001
TU_AGG_1000_INV	.371	.147	6.371	1	.012	1.450
TC_MULTI_INV_LN	.068	.183	.141	1	.708	1.071

Table 9-65: Test of Model Coefficients (INV2LIC)

-2 Log Likelihood	Overall (score)			Change From Previous Step			Change From Previous Block		
	Chi-square	df	Sig.	Chi-square	df	Sig.	Chi-square	df	Sig.
4749.658	240.750	18	.000	6.104	2	.047	6.104	2	.047

Table 9-66: Variables in the Equation (INV2LIC)

	B	SE	Wald	df	Sig.	Exp(B)
DUMMY_MECH	-.334	.349	.919	1	.338	.716
DUMMY_CHEM	1.020	.425	5.761	1	.016	2.772
DUMMY_BIOPHARM	.475	.518	.843	1	.359	1.609
DUMMY_MED	.097	.395	.061	1	.805	1.102
NUM_TOTAL_REF	.025	.013	3.676	1	.055	1.025
NUM_CLAIMS	.002	.002	.900	1	.343	1.002
IPC_NUM	-.004	.018	.053	1	.818	.996
TECH_AGE	-.005	.005	1.414	1	.234	.995
INV_PROJECT	.001	.190	.000	1	.994	1.001
INV_PARTNER	1.001	.109	84.787	1	.000	2.722
NUM_PREV_INV_1000	-.227	2.572	.008	1	.930	.797
NUM_PREV_LIC	.007	.003	7.266	1	.007	1.007
NUM_PREV_TTO	.002	.002	.851	1	.356	1.002
T_EMP_PER_COMP	.000	.003	.001	1	.977	1.000
T_INV_PER_COMP_1000	-.160	.051	9.843	1	.002	.852
T_VC_IND_REV	.002	.001	7.470	1	.006	1.002
TU_AGG_1000_INV	.052	.049	1.127	1	.288	1.053
TC_MULTI_INV_LN	-.195	.087	5.019	1	.025	.823