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Academic Spin-Off's Transfer Speed – Analyzing the Time from Leaving University to Venture

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Abstract:
For academic spin-offs I analyze the length of time between the founder's leaving of academia and the establishment of his firm. Technology transfer can take place even years after leaving the mother institution. A duration analysis reveals that a longer time-lag is caused by the necessity of assembling complementary skills, either by acquisition by a single founder or by searching for suitable team members. Furthermore, new ventures are established earlier if the intensity of technology transfer is high, the founders have access to university infrastructure, or received informal support by former colleagues.

Keywords: Academic spin-offs; technology transfer; skill complementarities

Jel codes: C41; J24; L26; M13

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1 Introduction

Technology transfer from public research institutions, i.e. the commercialization of research results, can take place through many different channels. One important channel is the formation of new firms which are based on research, knowledge or skills created in a public research institution[1]. Bercovitz and Feldmann (2006) identify the establishment of those firms, known as academic spin-offs, as one of the core mechanisms of university technology transfer besides sponsored research, licensing out of R&D results and hiring of students or researchers. Technology transfer can also proceed through other channels such as adoption of tacit knowledge or publications.

For licensing, Jensen and Thursby (2001) found that inventions are so "embryonic" at the time of licensing that it is not known whether the invention will become successfully commercialized. Most inventions require further development. In this development process inventor cooperation is crucial for commercial success. However, because of a moral-hazard problem with regard to inventor effort, there would be no further development unless the inventor's return and the licensee's output are linked. Jensen and Thursby propose royalties or equity participation as possible solutions to the moral-hazard problem. Academic spin-offs might be another solution to that kind of moral-hazard problem in technology transfer.

Other studies analyze why transfer channels often suffer from a low speed of technology transfer. Adams (1990) shows that there is an average lag of 20 years from the publication of academic research to its application by industry, whereas Mansfield (1995) finds that for a firm's product or process innovations, which could not have been developed in the absence of recent academic research, 7 years on average elapse between the finding of the relevant academic research results and the commercial introduction of the new product or process.

[1] Public research institutions include besides higher education institutes (e.g. universities or technical colleges) also public research organisations (e.g. Fraunhofer Society, Max Planck Society). In the following university, academia and public research institutions are synonyms.

There is a prevalent belief that academic spin-offs are established when the founder is employed at university or directly after she has left the academic institution. In a nutshell, Carayannis et al. (1998, p.3), state the naive view: "Typically, an employee [...] leaves the parent organization, taking along a technology that serves as entry ticket for the new company in a high-tech industry." In fact there is no clear definition of an academic spin-off. Some definitions even explicitly state that academic spin-offs are only those new ventures which have been founded during the time at the research institution or immediately after leaving science (e.g. Pirnay et al., 2003). But substantial technology transfer from academia can take place even years after a founder has left university as Egeln et al. (2003a) show. Early research even included those ventures which were not founded immediately as Pirney cites:
"Roberts considered a venture as a MIT spin-off even if there was a lag of up to nine years between leaving MIT or an affiliate labs and starting the company as long as the technological base of the company was related to research at the lab at the time of employment. (McMullan and Vesper, 1987, p.356)"
Although it is well known that spin-off companies can be started years after having left university, analysis is mostly restricted to those whose founders are still members of the university or have very recently left (e.g. Druilhe and Garnsey, 2004). In a first study for Germany, which tried to reveal both the scope of academic spin-off activities in research and knowledge-intensive industries as well as characteristics of academic spin-off firms, Egeln et al. (2003a) found that one in three spin-offs are established more than five years after the founder has left the academic institution.

This paper aims to analyze the factors that drive this time-lag in the establishment of academic spin-offs. A special focus is put on the existence of complementarities in skills needed to establish spin-off ventures as well as on the impact of the intensity of technology transfer. In my empirical analysis I will show that a longer time-lag is caused by the necessity of assembling complementary skills, either via learning by a single founder or by searching for suitable team members. Furthermore, I find that new ventures are established earlier if the intensity of technology transfer is high, the founders have access to university infrastructure, or informal support by former colleagues.

The paper is organized as follows: This introduction is followed by a short literature review of existing empirical spin-off literature. After that the hypotheses for the empirical analysis are developed, followed by section 4 where the data set is described. Section 5 carries out the empirical analysis and section 6 summarizes the findings and concludes the paper.

2 Literature review

The spin-off literature covers a wide field of different topics. Many studies investigate the spin-off phenomenon at the university level. These studies often take a policy view and ask how a region or university can enhance and facilitate spin-off activities (e.g., O'Shea et al., 2005; Powers and McDougall, 2005; Clarysse et al., 2004; Di Gregorio and Shane, 2003; Lockett et al., 2003; Franklin et al., 2001; Steffensen et al., 1999). Often benefits and effects for academia are also investigated. A study of Bray and Lee (2004) found, for example, that holding equity in university spin-offs creates, on average, a ten times higher income for US universities than licensing.

On the micro level characteristics, development and performance of academic spin-offs (Walter et al., 2006; Mueller, 2006) are examined. Besides employment growth, turnover growth, and fund raising (especially venture capital funding), survival is frequently examined. The patent stock at founding as well as the patent scope, for example, significantly increases an academic spin-off's probability of survival (Shane and Stuart, 2002; Nerkar and Shane, 2003).
Rothaermel and Thursby (2005b) found that the number of backward patent citations increases the total amount of funds raised, increases the probability of venture capital financing and lowers the firm's probability of failure.

Moreover, strong university linkages of spin-offs located in an incubator to the incubator-sponsoring university reduce the probability of failure but retard timely graduation as well (Rothaermel and Thursby, 2005a).

In some studies characteristics and performance measures of spin-offs are compared to those of non-academic start-ups. Egeln et al. (2003b) for example found that employment in the year of establishment is higher in academic spin-offs than in other ventures of research and knowledge-intensive industries. Furthermore, employment growth of academic spin-offs in the first years after the establishment is considerably higher than the employment growth of other new ventures. Dahlstrand (1997) even found that, after an initial ten-year period, spin-offs grew significantly faster than non-spin-offs. But evidence is mixed: Ensley and Hmieleski (2005) showed that university-based start-ups perform significantly worse than their independent counterparts in terms of revenue growth and cash flow. Similarly Egeln et al. (2007) found that Austrian academic spin-offs have higher probabilities of surviving but do not perform better in terms of employment or turnover growth.

The first typology was provided by Pirnay et al. (2003), summarizing prevalent definitions of spin-off activities.

The location decision of academic spin-offs was investigated in detail by Egeln et al. (2004). Theory suggests that in order to benefit from knowledge-spillover effects spin-offs should locate close to their incubator institution. Egeln et al. (2004) found instead that proximity to incubators is less important for location decisions of German academic spin-offs. Fewer studies examined the spin-off process (Ndonzuau et al., 2002), which help to explain the differences in the time that elapses after the founder has left university.

Time is a rather disregarded factor in the literature of technology transfer, especially in the spin-off literature. Markman et al. (2005) do explicitly focus on the time factor. They investigate the determinants and effects of innovation speed in university licensing measured as the time elapsed between the disclosure of an invention and the licensing of that invention.

Very few studies give some hints about the impact of being still employed in university after founding a company on firm performance, but they are based on a very small sample size of eight or twelve spin-offs (Olofsson and Wahlbin, 1984; Doutriaux, 1987). To the best of my knowledge there are no studies which have investigated the determinants of the length of the time period that elapses after the founder(s) had left university.

3 Hypothesis development

As technology transfer by means of establishing a company is a complex process with different stages there may be many factors influencing the time that elapses between leaving university and the establishment of a spin-off.

Theoretical explanations on why some founders of academic spin-offs established their firm later than others can be borrowed from the theory developed by Lazear (2004) who explains which people are more likely to establish a business. Lazear's theoretical model states that an entrepreneur has to be jack-of-all-trades. This means that an entrepreneur is less specialized and more a generalist as he must have, at least on a basic level, some knowledge of a wide variety of business areas. Hence, people who tend to become entrepreneurs should have a particular strategy on how to invest in their own human capital. Those whose initial skill endowment is unbalanced should invest in skills in which they are weak. Even those with balanced skills will invest in their skills if the prospective income gain exceeds the marginal costs. Lazear's theory is therefore based on skill complementarities which are especially relevant for entrepreneurs.

If complementarities actually exist, for example, between engineering and management skills, founders have to acquire a whole set of competencies or search for other specialized team members. A scientist with an unbalanced skill profile has to first acquire complementary skills like management skills before establishing her own venture becomes worthwhile. This is time consuming and affects the length of time between the drop out of academia and the point in time when the venture was established. After leaving a public research institution scientists with a balanced skill profile will therefore venture more quickly than scientists with an unbalanced skill profile.

Acquiring a whole set of knowledge and searching for other specialized team members can be viewed as substitutes. The formation of a team of founders is thus a useful alternative to acquiring the needed complementary skills by the founder herself. Furthermore, to venture more quickly it may be necessary that either a single founder or a team demonstrates a skill profile that is characterized by a combination of skills rather than by specialization in one single subject. Thus the first hypothesis can be expressed as follows:

Hypothesis 1a: *Spin-offs established in teams have shorter time-lags between the drop out of academia and the establishment of the spin-off.*

Hypothesis 1b: *A combination of different skills leads to shorter time-lags than a homogenous skill profile.*

Concerning the technology or knowledge they transfer, academic spin-offs are quite heterogenous. With regard to the type of knowledge transferred one can distinguish between research results, new developed methods, and skills acquired at university. These types differ primarily in their specificity of knowledge. While new research results usually have a quite narrow application range for commercial exploitation, the scope is wider for methods and widest for competencies acquired in academia. It is reasonable to assume that the time which elapses after leaving university is highly influenced by the type of knowledge which is transferred. An example will help to illustrate that idea: When the establishment is based on new research findings a spin-off should be founded closer to the time of leaving academia than when the establishment is based on specific skills acquired at university. The finding of new research results usually opens a *"window of opportunity"* during which the opportunity has to be exploited before the window is "closed" by competitors. This window of opportunity might be rather short depending on the technology developed. Since skills are bounded to the individual and can less easily copied by others, the exploitation of individual skills and competencies acquired in academia will in general have a window of opportunity which is much larger than that of successful exploitation of new research results. Hence for securing the competitive advantage the time factor is of more interest when research results are sought to be transferred in marketable products or services than skills.

The second hypothesis can therefore be formulated in terms of intensity of technology transfer.

Hypothesis 2: *Spin-offs with a higher intensity of technology transfer have shorter time-lags.*

4 Database and Descriptive Statistics

For the following empirical analysis a survey of more than 20,000 German start-ups in research and knowledge-intensive industries founded between 1996 and 2000 is used as data set. In 2001 a computer-assisted telephone survey was conducted in order to estimate both the number of academic spin-offs in Germany and to identify the core characteristics of academic spin-offs. The underlying population from which a stratified random sample was drawn consists of all the new ventures in research and knowledge-intensive industries[2] which had been established between 1996 and 2000. Stratification criteria are the industry, the year of establishment, and the type of region where the start-up was established. Data concerning all start-up companies in Germany could have been retrieved from the Mannheim Foundation Panel

[2]Research and knowledge-intensive industries include cutting edge technology (e.g. manufacturing of pharmaceutical products), high technology (e.g. manufacturing of chemicals), technological services (e.g. telecommunications) and knowledge-intensive services (e.g. business consulting). A classification based on NACE codes is provided in appendix E. Other industries are excluded since it is assumed that only a small fraction of academic spin-offs are founded there.

which is built upon firm level data made available by CREDITREFORM[3]. One major advantage of that survey is the way academic spin-offs are identified. Instead of asking technology-transfer offices about spin-off activity at their research institutions, founders themselves were asked about their academic background and the role of technology transfer for establishing their business. Technology-transfer offices and heads of institutions might both have limited information about the total amount of spin-off activities at their institutions. In addition they lack information about the characteristics of the founder or the start-ups. Especially for spin-offs that are established years after the founders have left university, the institutions will hardly know about.

During the interview each start-up was asked about the academic background of the founders and the relevance of academic skills, new scientific methods and results of the founders' own research activities in the establishment process. Academic spin-offs are then those foundations of persons with an academic background (students, graduates and researches) which classified academic skills, new scientific methods or own research results as *indispensable* for the establishment of their firm. A similar approach was used by Mansfield (1995) to identify technology transfer from academic research concerning the development of new products and processes.

According to these statements three types of spin-offs could be distinguished which differ in their intensity of technology transfer.

Research-transfer spin-offs: New *research results* developed by at least one of the founders must have been indispensable to the creation of the firm (highest intensity of technology transfer).

Method-transfer spin-offs: New *scientific methods*, which at least one of the founders acquired during the time at the public research institute,

[3] CREDITREFORM is Germany's major credit rating agency, collecting information about almost all German firms for the purpose of providing information about a firm's financial standing (more detailed information on the Mannheim Foundation Panels is provided by Almus et al. (2000)).

must have been indispensable to the creation of the firm (medium intensity of technology transfer).

Competence spin-offs: Merely *specific skills*, which at least one of the founders acquired during the time at the public research institute, must have been indispensable to the creation of the firm (lower intensity of technology transfer).

For each academic spin-off, information on the name of the academic institution(s) the founders studied or worked, the time when the last founder left this institution and the academic disciplines of their studies or research was obtained. Furthermore, general facts about the firm (for example, start-up size, turnover, employment, R&D activities) were retrieved during the interview.

Using the above described methodology, out of the total number of start-ups surveyed (20,241), 1,810 spin-offs have been identified and the time their founders needed to venture can be analyzed. Out of these 1,810 academic spin-offs 15% are research-transfer spin-offs, 23% method-transfer spin-offs and 62% competence spin-offs.

For all spin-offs, whose founders had, up to the time of the survey, already left the public research institute, a kernel density estimation for the time which elapsed between leaving academia and establishment of the spin-off was calculated using the Epanechnikov kernel function. The corresponding graph of the kernel density estimation and the histogram of the time-lag is displayed in Figure 1. The time can even take negative values. This identifies academic spin-offs, in which at least one of the founders was still in academia after the venture was established. The univariate kernel density estimation shows that the distribution of the time to venture is positively skewed. Although the maximum of the density function is roughly around zero, a high density of time-lags of over 5 years signals that spin-off establishments beyond a time-lag of 5 years are rather probable. One can also see that even time-lags beyond 10 years are relatively probable.

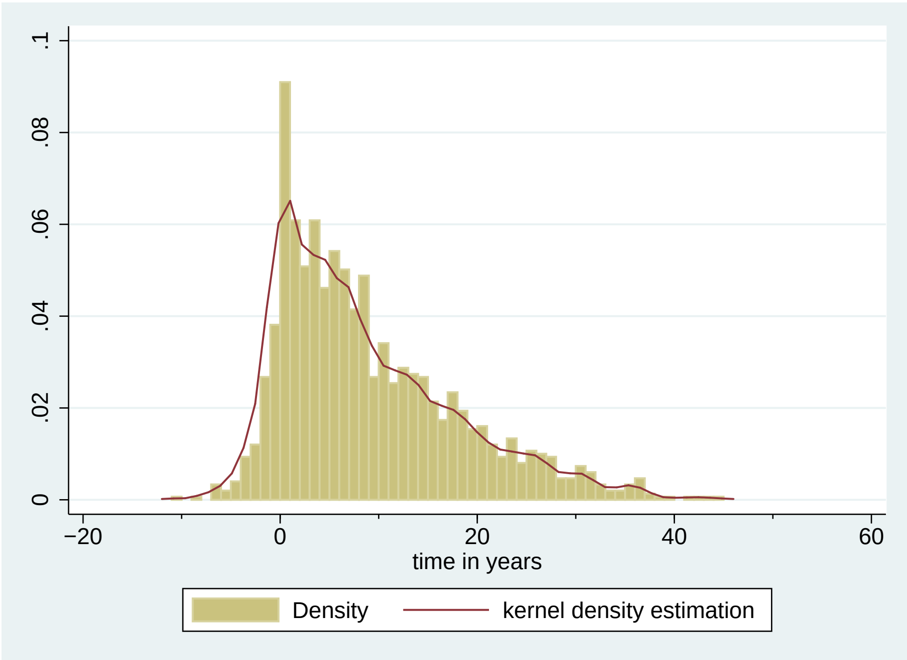

Figure 1: Histogram and kernel density estimation of the time to venture

Source: ZEW Spin-Off Survey 2001, author's calculactions.

The knowledge and technology transfer via the spin-off establishment is therefore not restricted to those who establish their firm directly after leaving university. Even many years after leaving a public research institute, knowledge and technology transfer may still take place.

Furthermore, descriptive statistics about the time-lag between leaving university and spin-off establishment are given in Table 1. Only about 33% of the spin-offs were established with a time-lag below one year, as one can conclude from the fourth column. For ventures, which were founded a year or more after the founder left university, the period of time which elapsed in between was, on average, around 11 years.

Moreover the descriptive statistics reveal substantial differences in the founding time-lag between the different spin-off types. Spin-offs with higher intensity of technology transfer seem to be established closer to the year

Table 1: Time-lag between leaving university and establishing a spin-off

time-lag	*Type of spin-off* research-transfer spin-off	method-transfer spin-off	competence spin-off	all
founder(s) still in science	$41\%^{A,B}$	$28\%^{B,C}$	$21\%^{A,C}$	25%
established in the year after leaving	$10\%^{A}$	$10\%^{C}$	$6\%^{A,C}$	8%
mean (median) time-lag for positive values of time-lags	10.1 (7)	10.3 (7)	11.2 (9)	10.9 (8)

Notes: Median in parentheses; *A:* significant differences between research-transfer spin-offs and competence spin-offs, *B:* significant differences between research-transfer spin-offs and method-transfer spin-offs, *C:* significant differences between method-transfer spin-offs and competence spin-offs.

Source: ZEW Spin-Off Survey 2001, author's calculations.

university was left.

Descriptive statistics on foundation and founder characteristics included in the econometric analysis are presented in Table 2. Around 60 percent of all spin-offs were founded in teams.

Spin-offs can be further distinguished by the founders' positions in the respective research institutes. If none of the founders has been a researcher the spin-off is named graduate spin-off. While 35 percent of research-transfer spin-offs were founded by persons who have not been employed at a public research institute, the fraction for method-transfer spin-offs and competence spin-offs is much higher (64 percent and 75 percent respectively). Overall 66 percent of the spin-offs had no researchers in the founding team.

For the following analysis five different motivations to start a firm can be distinguished, while it is possible that multiple motivations apply to the founders' decision to start a firm. Founders can be driven by the economic potentials provided by research results, by the motivation to work independently and self-determined, by the motivation to improve one's personal income prospectives, by better career options than in academia, and by a specific corporate demand for products or services. Statistically significant differences between research-transfer spin-offs and competence spin-offs appear for the motivations to exploit economic potentials provided by research results and to achieve better career options than in academia. To use the economic potential is the case for 17 percent of all competence spin-offs compared to 55 percent of research-transfer spin-offs. Better career options than in academia is only a minor motivation for competence spin-offs (9 percent) whereas career options seem to be more common for research-transfer spin-offs (24 percent).

Spin-offs might have received different kinds of support from their academic institutions prior to firm formation. Assistance may vary from courses, infrastructure and individual legal and business advice to the establishment of contacts and encouragement and support from colleagues. Around 6 percent made use of courses and teaching events relevant for the founding process while 4 percent received individual legal or business advice. Provision of infrastructure (offices, secretarial service, access to laboratories etc.), establishment of contacts and encouragement and support from colleagues was the more frequently used the higher the intensity of technology transfer. 26 percent of research-transfer spin-offs got support from colleagues while only 16 percent of method-transfer spin-offs and 10 percent of competence spin-offs received that kind of support. This applies for the provision of infrastructure and establishment of contacts, too. 12 percent of research-transfer spin-offs, but only 5 percent and 3 percent of method-transfer spin-offs and competence spin-offs respectively, were supported with infrastructure. Contacts were established for 10 percent of all research-transfer spin-offs, but just for 7 percent (5 percent) of all method-transfer spin-offs (competence spin-offs). These differences can be explained by a selection process of the supporting university because high-potential start-up ideas are supported preferentially.

The founder(s) studied mostly one single subject (76 percent). Subject combinations are divided into four categories: a combination of natural science and engineering, a combination of natural science and business, a combination of engineering and business, and other combinations. With a fraction of about 13 percent other combinations are the most frequent category. The corresponding fractions of the other categories classified by the spin-off type can be inferred from Table 2 as well. Even if an spinoff was not established by a team of founders, the founder could have studied various subjects. In fact, 4% of all single founders show a combination of subjects. The other way around, team foundations do not necessarily show a combination of different subjects.

Research and knowledge intensive industries can be further subclassified into six industries: the cutting edge technology industry, the high technology industry, the software industry, technological services, knowledge intensive services and other manufacturing industries. The majority of the firms operate in technological services (38 percent), closely followed by knowledge intensive services (37 percent). Altogether 7 percent operate in cutting edge technologies, while the fraction of research-based transfer spin-offs operating in cutting edge technology is almost twice as high (13 percent).

Table 2: Descriptive statistics

variable	*Type of spin-off* research-transfer spin-off	method-transfer spin-off	competence spin-off	all
team	57%	58%	61%	60%
graduate	35%	64%	75%	66%
Motivations to start the firm				
economic potentials	55%	31%	17%	26%
self-determined working	88%	93%	93%	92%
income	60%	66%	65%	64%
career	24%	13%	9%	12%
demand	50%	51%	48%	49%
Received support from academic institutions				
courses	6%	8%	5%	6%
infrastructure	12%	5%	3%	5%
advisory	5%	5%	3%	4%
contacts	10%	7%	5%	6%
colleagues	26%	16%	10%	14%
Academic subjects				
nat & engin	4%	4%	4%	4%
nat & business	5%	5%	4%	5%
engin & business	1%	4%	3%	3%
other combination	11%	11%	14%	13%
single subject	78%	77%	75%	76%
Industry				
cutting edge technology	13%	4%	6%	7%
high technology	7%	4%	5%	5%
other manufacturing	7%	5%	5%	5%
software	9%	9%	8%	8%
technological services	34%	40%	38%	38%
knowledge intensive services	30%	38%	38%	37%

Notes: Cutting edge technologies (high technologies) are those sectors defined by Grupp and Legler (2000) after 4 digit NACE classification in which the average R&D intensity is above 8% (3.5%-8%).

Source: ZEW Spin-Off Survey 2001, author's calculations.

5 Empirical Analysis

5.1 Estimation Method

In order to analyze the time to the occurrence of an event it is appropriate to deviate from the normality assumption and use techniques of survival analysis. To estimate the effect of certain covariates $\mathbf{x}_j$ on the hazard rate $h(t|\mathbf{x}_j)$, which is the instantaneous rate of failure[4] at a given time t or the age specific failure-rate, most commonly proportional hazard models, expressed by

$$h(t|\mathbf{x}_j) = h_0(t) \exp(\boldsymbol{x}_j \boldsymbol{\beta}_x),$$

are used.

As the baseline hazard $h_0(t)$[5] is time-dependent, but not influenced by the covariates, each individual (firm) faces the same baseline hazard. Because of that, comparing subject j to subject m, one obtains from the model

$$\frac{h(t|\mathbf{x}_j)}{h(t|\mathbf{x}_m)} = \frac{\exp(\boldsymbol{x}_j \boldsymbol{\beta}_x)}{\exp(\boldsymbol{x}_m \boldsymbol{\beta}_x)},$$

which is called hazard ratio. The hazard ratio is constant, assuming that the covariates x_j and x_m do not change over time.

From the formulation of the hazard rate it is easy to see that for a binary covariate x_k shifting from zero to one the hazard ratio is

$$\frac{h(t|\mathbf{x}_j, x_k = 1)}{h(t|\mathbf{x}_j, x_k = 0)} = \frac{\exp(\boldsymbol{x_j \beta_x} + 1 \cdot \beta_k)}{\exp(\boldsymbol{x_j \beta_x})} = \exp(\beta_k),$$

which gives the coefficients an easy interpretation. As a semi-parametric estimation method proposed by Cox (1972) imposes no restrictions on the

[4]The risk of failure is the risk of the occurrence of the event under investigation, i.e. here the "risk" of establishing the spin-off.

[5]The baseline hazard is the hazard rate of observations with zero covariates. The covariates shift the baseline hazard multiplicatively.

shape of the baseline hazard and therefore allows the baseline hazard to be as flexible as possible, Cox regression is used for this analysis.

Using survival analysis the time under investigation is not allowed to take negative or zero values. Additionally, for those founders who were still in science when the survey was conducted one just knows that the time value is negative. The exact value of these negative time-lags is not known. Therefore, concerning the dependent variable no difference is made between all spin-off establishments which are founded in the time when the founder was still in academia. These observations are assumed to enter and "fail" immediately and a time value of 0.1 was assigned to them. Similarly all firms whose founders left academia in the year of establishment (original time value of zero) got a new time-value of 0.2. For all other observations (these with a time-lag) the time-lag was measured in years. This procedure is possible because the Cox proportional hazards model is sensitive only to the order of the failure events. Thus as long as one keeps the earliest failure events as occurring first, the results will remain unchanged (Gould, 1999). Furthermore, no relevant information is lost as the focus of the analysis lies on the explanation of rather large positive time-lags. The robustness of this procedure is tested and approved by different transformations of the time under investigation which all yield exactly the same results in the Cox regression.[6]

In order to test Hypothesis 2 the intensity of technology transfer is measured by the different spin-off types. The effect of complementarities in skills (Hypotheses 1a and 1b) is captured by a dummy variable which indicates if the spin-off was established by a team and a set of dummy variables which display the combination of subjects the founder(s) studied, provided the founder(s) did not study a single subject[7].

But the time lag between leaving university and establishing the firm

[6] Details on the transformation and the resulting regression results can be found in the appendix C.

[7] These are different aspects as one founder could have studied several subjects of a team of founders could have studied the same subjects.

can be influenced by several other factors. To capture these effects a wide set of further dummy variables is included in the analysis. These dummies portray if the founders were students or researchers during their time in academia (dummy "graduate" for non-researchers), which motivations had driven the establishment, what kind of support the founders received from their academic institution, and to which economic sector the spin-off belongs.

Tests based on Schoenfeld residuals (Schoenfeld, 1982; Grambsch and Therneau, 1994) reveal some violations of the proportional hazard assumption concerning the covariates *method-transfer spin-off* and *graduate*. Therefore another model (model B) is estimated with the same specification as in the original model (model A) but stratified by the variables *method-transfer spin-off* and *graduate*. In contrast to the standard Cox model, which assumes proportional hazards for each explanatory variable, a stratified model makes it possible to control for the effect of a certain variable without making a proportional hazard assumption for that variable (Parmar and Machin, 2006). Stratification allows for different baseline hazards for each of the possible categories[8] but constrains the coefficients to be the same. The model is now relaxed in favour of

$$h(t|\boldsymbol{x}_j) = h_{0i}(t)exp(\boldsymbol{x}_j\boldsymbol{\beta}_x), \qquad \text{if } j \text{ is in group } i, \;\; i = 1, 2, 3, 4.$$

Tests on the proportional hazard assumption do not reveal further violations. Because analysis in model B is stratified by the variables *method-transfer spin-off* and *graduate* the effect of these variables is now absorbed by different shapes of the baseline hazard and no coefficients are estimated.

[8] Because *graduate* and *method-transfer spin-off* are binary, four combinations appear and the model allows four different baseline hazards.

5.2 Estimation Results and Discussion

Estimation results of the Cox regressions for both models are summarized in Table 3. Both coefficients and standard errors are presented. As reference categories the categories with the highest fraction are used (competence spin-off, single academic subject profile, technological services). Between the two models the coefficients considerably change neither in magnitude nor in significance which indicates that the violation of the proportional hazard assumption in model A was not severe.

Both hypotheses stated in section 3 can be supported by the data. The hazard ratio for the team dummy is $\exp(0.205) = 1.23$. This means that the hazard increases by 23% if the spin-off is founded by a team instead of a single founder. Hence the time lag is considerably shorter for spin-offs established by a team of founders. Significant positive effects of two of the subject combination dummies show that the time-lag is highest for those who studied one single subject, which is the reference category. Combinations like natural science with engineering or business have considerably higher hazards, i.e. the probability that the spin-off establishment takes place is higher for those combinations than for a single founder at any point in time. The hazard increases by 24 percent or 23 percent, respectively, compared to those spinoffs which were founded without subject combinations. These effects support the assumption that complementarities in skills are present and notably relevant in the establishment process of academic spin-offs.

In addition to acquiring complementary skills by team formation the positive effect of teams on transfer speed can also be explained by the pooling of financial resources and risk-sharing among the team members both of which reduce the risk faced by the individual founder.

Furthermore a research-transfer spin-off has a hazard which is $\exp(0.140) - 1 = 15\%$ higher than the hazard of a competence spin-off. A spin-off with a higher intensity of technology transfer is therefore established more "quickly". This supports Hypothesis 2.

Table 3: Cox Regression on the time-gap

	(1) Model A			(2) Model B		
	coefficient		standard error	coefficient		standard error
research-transfer spin-off	0.171	**	(0.073)	0.140	*	(0.074)
method-transfer spin-off[1)]	0.089		(0.059)	–		–
team	0.199	***	(0.054)	0.205	***	(0.054)
graduate	-0.452	***	(0.064)	–		–
Motivations						
economic potential	0.116	*	(0.059)	0.113	*	(0.060)
self-determined working	0.235	***	(0.090)	0.222	**	(0.091)
income	-0.024		(0.050)	-0.017		(0.050)
career	0.032		(0.085)	0.042		(0.086)
demand	0.010		(0.048)	0.008		(0.048)
Support						
courses	0.171		(0.107)	0.150		(0.107)
infrastructure	0.388	***	(0.124)	0.324	***	(0.124)
advisory	0.064		(0.125)	0.030		(0.125)
contacts	-0.124		(0.108)	-0.115		(0.108)
colleagues	0.461	***	(0.077)	0.432	***	(0.078)
Subjects/Disciplines[2)]						
nat & engin	0.231	*	(0.129)	0.213	*	(0.130)
nat & business	0.208	*	(0.116)	0.203	*	(0.117)
engin & business	-0.253	*	(0.150)	-0.231		(0.152)
other combination	0.040		(0.076)	0.055		(0.077)
Industry[3]						
cutting edge technology	-0.140		(0.101)	-0.149		(0.102)
high technology	-0.263	**	(0.111)	-0.273	**	(0.111)
software	0.337	***	(0.092)	0.323	***	(0.092)
knowledge intensive services	-0.097	*	(0.055)	-0.100	*	(0.056)
other manufacturing	-0.429	***	(0.109)	-0.428	***	(0.110)
N	1810			1810		
Log likelihood	-11754			-9745		
χ^2	296			146		

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

1) reference category: competence spin-off, 2) reference category: single academic subject profile 3) reference category: technological services

Source: ZEW Spin-Off Survey 2001, author's calculations.

Further, the coefficients of the control variables reveal some interesting insights. Among potential motivations for the spin-off establishments, the motive to work independently and making one's own decisions speeds up establishment, which is quite intuitive. The hazard for founders driven by this motivation was about 25% higher. Likewise the motivation to take promising economic opportunities provided by research results has a positive influence on the technology transfer speed. Those who were motivated by the economic potential provided by research results have a hazard which is 12% higher. This motivation might accompany the findings about the effects of transfer intensity.

Concerning the support received from academic institutions, significant influence can be found for infrastructure support and encouragement by colleagues and professors. While the provision of infrastructure influences the time-lag substantially, the encouragement of colleagues, which is more a soft-kind support, is even more important for the acceleration of technology transfer through academic spin-offs. The provision of infrastructure increases the hazard by 38% while encouragement of colleagues increases the hazard by 54%.

These two kinds of university support differ materially. Support of infrastructure is an institutionalized assistance and positive effects on transfer speed are quite obvious as start-up costs are reduced substantially when existing infrastructure can be utilized. The explanation for the rather large effect of encouragement of colleagues and professors is not that obvious. The results of the empirical analysis suggests that psychologic factors such as peer support and climate effects are rather important in the start-up decision process. First, encouragement of colleagues helps opportunity identification. Somebody who has never thought about being self-employed will need much more time to recognize his research results or skills as having the potential to be commercialized by the establishment of a new firm. The idea that his former scientific work provides the basis for a business idea might not show itself until the researcher has gained some market experience. If the scientist got

in contact with some "spirit of entrepreneurship" during his time at academia this recognition process will be substantially accelerated. In this context colleagues act as guides.
Second, support from colleagues means professional assistance, too. Besides the possible acceleration of the opportunity identification process by support from colleagues, the founder knows that she can fall back on the knowledge of former colleagues on an informal basis.

The sector dummies show that there are also substantial technology transfer speed differences between the sectors. Academic spin-offs operating in the software industry are established closest to the time being in academia. To explain that result one has to remember that all spin-offs in the sample had been established between 1996 and 2000, the time of the "New Economy boom". During that time it was rather easy for firms in information technologies, especially for software-firms, to find an investor and receive funding. A fact which accelerates foundation substantially.

As the variable method-transfer spin-off is insignificant in model A, no valuable information is lost by using this covariate as stratification criteria in model B. But model A indicates that the academic status of the founder when he obtained the results or skills, which have been essential for the business idea, has a significant impact on transfer speed. If the founder was not a researcher but a graduate or student, the hazard is about 36% lower in model A. The time-lag is thus longer for "graduates only" founders.[9] This result is quite intuitive as students and graduates, which have never worked in an research institution, have not spent as much time in science as researchers. Hence "graduates only" founders must use market experience as a substitute for the experiences a researcher could gain in academia. Although the stratified Cox regression cannot give a precise estimate about the magnitude of the effect of the academic status, a comparison of the estimated cumulative baseline hazards supports the the findings of model A. The cumulative

[9] The lower the risk of "failure" the longer the time between leaving academia and establishment.

baseline hazard of researchers lies above the cumulative baseline hazard of establishments which are made only by graduates (see appendix A).

As a goodness of fit measure an evaluation based on Cox-Snell residuals (Cox and Snell, 1968) was used.[10] For both models a good fit could be observed (see appendix B), but the unstratified model (model A) has a slightly better fit than the stratified model (model B).

In order to test the robustness of the results and to get a more concrete interpretation of the influence of skill complementarities and the intensity of technology transfer on the time spread between academia and firm establishment the model was also estimated by a Heckman Selection Model (see appendix D). A higher intensity of technology transfer speeds up foundation by 0.9 years. Also in the Heckman Selection Model team foundations have shorter time-lags. For establishments in teams the time-lag is 1.3 years less on average.

6 Conclusions

This paper focuses on the phenomenon that a large amount of technology transfer by means of academic spin-off creation is done years after the respective founders had left the academic institution. A fact which was in general known but ignored in the existing spin-off literature. This "late" technology and knowledge transfer is not unimportant. New academic research results, methods or skills obtained by founders in research and knowledge intensive industries had been indispensable for the creation of the spin-off even more than ten years after the institution was left. Policy makers should therefore not only concentrate on direct spin-off activity but also develop appropriate programmes for academic persons who first acquired complementary compe-

[10] For models which fit the data well the Cox-Snell residuals ought to have a standard exponential distribution with a hazard function of one for all t. Accordingly the cumulative hazard of the Cox-Snell residuals should form a straight 45 degree line. The cumulative hazard function of the Cox-Snell residuals is usually estimated using the Nelson-Aalen estimator.

tencies such as market experience.

The empirical analysis shows that skill complementarities are likely to be present in the spin-off establishment process. This conclusion is drawn from both the fact that the time-lag of spin-off establishments in teams is shorter than the time-lag of single founders and from the positive effect that certain combinations of academic subjects have on transfer speed. As team foundations have significantly shorter time-lags, a good matching of potential founders with persons with a complementary skill profile can foster spin-off creation. Policy makers as well as technology transfer offices should take that into account and offer assistance in the matching process.

Additionally, the intensity of technology transfer appears to speed up the transfer process due to a smaller "window of opportunity". For example, because of potential imitation, spin-offs with a high intensity of technology transfer were established earlier than those with a low intensity of knowledge transfer.

The positive influence of university infrastructure support and support from colleagues and professors on transfer speed give further suggestions to policy makers on how to encourage direct spin-off establishment. While more formal support by means of providing infrastructure helps to speed up spin-off formation, "peer support" by means of encouragement of colleagues and professors is also crucial factor for the time-dimension in the spin-off process.

As this paper assumes that the founders acquire complementary skills in the time between academia and spin-off formation it would be interesting for further research to know which competencies exactly can be termed complements. Is market experience, management experience or professional research experience in commerce of higher relevance? What are the influences of general life experience and periods of unemployment? Furthermore, the reasons for very long time-lags, such as time-lags of more than ten years, and the consequences of such long time-lags on firm-performance can be investigated. Thus, a lot of open questions concerning the time-lag remain which should be addressed in the future.

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Appendix

Appendix A

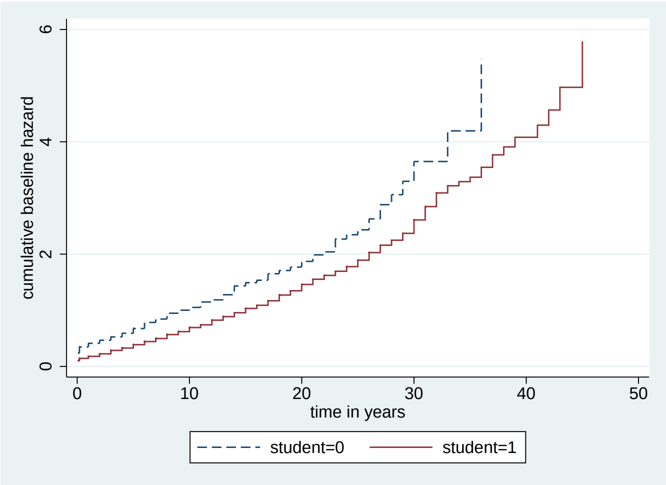

Figure 2: Cumulative baseline hazards if method-based transfer spin-off = 0

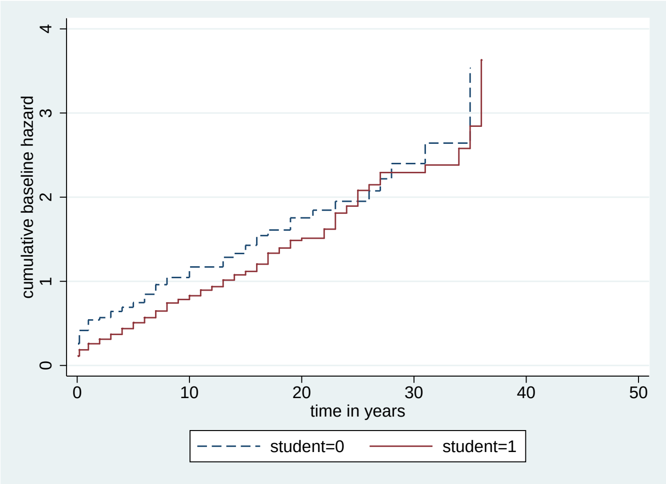

Figure 3: Cumulative baseline hazards if method-based transfer spin-off = 1

Source: ZEW Spin-Off Survey 2001, author's calculations.

Appendix B

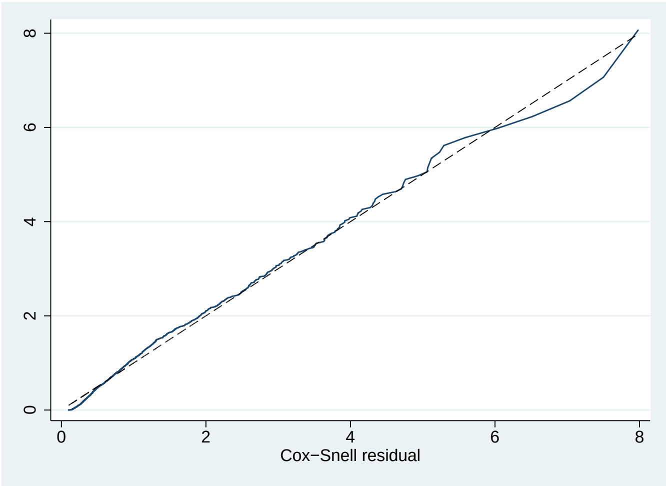

Figure 4: Goodness of fit model A

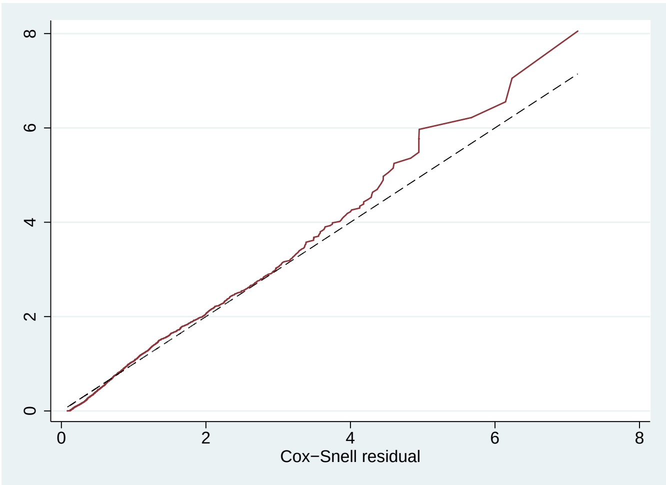

Figure 5: Goodness of fit model B (stratified model)

Source: ZEW Spin-Off Survey 2001, author's calculations.

Appendix C

In order to test the robustness of the procedure to assign a time value of 0.1 to all firms which have a negative time value and to those firms whose founder(s) have still been in science when the survey was conducted (no time-value, but for sure a negative one) and to assign a value of 0.2 to those firms which have been established in the same year when the (last) founder left academia (original time-value of zero) the same model specification was estimated for other possible data transformations.
The following transformations were made:

Transformation 1:

Cases:	new value	old value
Founders still in science:	time=0.12	time=0.1
Firm was established in the year of leaving:	time=0.25	time=0.2
Time-lag of one year:	time=1.3	time=1

Transformation 2:

Cases:	new value	old value
Founders still in science:	time=0.001	time=0.1
Firm was established in the year of leaving:	time=0.24	time=0.2
Time-lag of one year:	time=1.7	time=1
Time-lag of two years:	time=2.5	time=2

Transformation 3:

Cases:	new value	old value
Founders still in science:	time=0.001	time=0.1
Firm was established in the year of leaving:	time=0.24	time=0.2
Time-lag of one year:	time=1.7	time=1
Time-lag of two years:	time=2.5	time=2
Time-lag three years and more:	time=# years +0.034	time= # years

Table 4: Robustness to transformations of the time under investigation - Cox Regressions on the time-gap Model A

	Transformation (1) Model A		Transformation (2) Model A		Transformation (3) Model A	
research-tso	0.171**	(0.073)	0.171**	(0.073)	0.171**	(0.073)
method-tso[1)]	0.089	(0.059)	0.089	(0.059)	0.089	(0.059)
team	0.199***	(0.054)	0.199***	(0.054)	0.199***	(0.054)
graduate	-0.452***	(0.064)	-0.452***	(0.064)	-0.452***	(0.064)
Motivations						
econ. potent.	0.116*	(0.059)	0.116*	(0.059)	0.116*	(0.059)
self-determ. work.	0.235***	(0.090)	0.235***	(0.090)	0.235***	(0.090)
income	-0.024	(0.050)	-0.024	(0.050)	-0.024	(0.050)
career	0.032	(0.085)	0.032	(0.085)	0.032	(0.085)
demand	0.010	(0.048)	0.010	(0.048)	0.010	(0.048)
Support						
courses	0.171	(0.107)	0.171	(0.107)	0.171	(0.107)
infrastructure	0.388***	(0.124)	0.388***	(0.124)	0.388***	(0.124)
advisory	0.064	(0.125)	0.064	(0.125)	0.064	(0.125)
contacts	-0.124	(0.108)	-0.124	(0.108)	-0.124	(0.108)
colleagues	0.461***	(0.077)	0.461***	(0.077)	0.461***	(0.077)
Subjects/Disciplines[2)]						
nat & engin	0.231*	(0.129)	0.231*	(0.129)	0.231*	(0.129)
nat & bus	0.208*	(0.116)	0.208*	(0.116)	0.208*	(0.116)
engin & bus	-0.253*	(0.150)	-0.253*	(0.150)	-0.253*	(0.150)
other comb.	0.039	(0.076)	0.039	(0.076)	0.039	(0.076)
Industry[3]						
cutting edge techn.	-0.140	(0.101)	-0.140	(0.101)	-0.140	(0.101)
high technology	-0.263**	(0.111)	-0.263**	(0.111)	-0.263**	(0.111)
software	0.337***	(0.092)	0.337***	(0.092)	0.337***	(0.092)
knowl. int. services	-0.097*	(0.055)	-0.097*	(0.055)	-0.097*	(0.055)
other manufact.	-0.429***	(0.109)	-0.429***	(0.109)	-0.429***	(0.109)
N	1810		1810		1810	
Log likelihood	-11754		-11754		-11754	
χ^2	295.912		295.912		295.912	

Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

1) reference category: competence spin-off, 2) reference category: single academic subject profile 3) reference category: technological services

Source: ZEW Spin-Off Survey 2001, author's calculations.

Table 5: Robustness to transformations of the time under investigation - Cox Regressions on the time-gap Model B

	Transformation (1)		Transformation (2)		Transformation (3)	
	Model B		Model B		Model B	
research-tso	0.140*	(0.074)	0.140*	(0.074)	0.140*	(0.074)
method-tso[1)]	–	–	–	–	–	–
team	0.205***	(0.054)	0.205***	(0.054)	0.205***	(0.054)
graduate	–	–	–	–	–	–
Motivations						
econ. potent.	0.113*	(0.060)	0.113*	(0.060)	0.113*	(0.060)
self-determ. work.	0.222**	(0.091)	0.222**	(0.091)	0.222**	(0.091)
income	-0.017	(0.050)	-0.017	(0.050)	-0.017	(0.050)
career	0.042	(0.086)	0.042	(0.086)	0.042	(0.086)
demand	0.008	(0.048)	0.008	(0.048)	0.008	(0.048)
Support						
courses	0.150	(0.107)	0.150	(0.107)	0.150	(0.107)
infrastructure	0.324***	(0.124)	0.324***	(0.124)	0.324***	(0.124)
advisory	0.030	(0.125)	0.030	(0.125)	0.030	(0.125)
contacts	-0.115	(0.108)	-0.115	(0.108)	-0.115	(0.108)
colleagues	0.432***	(0.078)	0.432***	(0.078)	0.432***	(0.078)
Subjects/Disciplines[2)]						
nat & engin	0.213*	(0.130)	0.213*	(0.130)	0.213*	(0.130)
nat & bus	0.203*	(0.117)	0.203*	(0.117)	0.203*	(0.117)
engin & bus	-0.231	(0.152)	-0.231	(0.152)	-0.231	(0.152)
other combination	0.055	(0.077)	0.055	(0.077)	0.055	(0.077)
Industry[3]						
cutting edge techn.	-0.149	(0.102)	-0.149	(0.102)	-0.149	(0.102)
high technology	-0.273**	(0.111)	-0.273**	(0.111)	-0.273**	(0.111)
software	0.323***	(0.092)	0.323***	(0.092)	0.323***	(0.092)
knowl. int. services	-0.100*	(0.056)	-0.100*	(0.056)	-0.100*	(0.056)
other manufact.	-0.428***	(0.110)	-0.428***	(0.110)	-0.428***	(0.110)
N	1810		1810		1810	
Log likelihood	-9745		-9745		-9745	
χ^2	146		146		146	

Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

1) reference category: competence spin-off, 2) reference category: single academic subject profile 3) reference category: technological services

Source: ZEW Spin-Off Survey 2001, author's calculations.

Appendix D

Table 6: Heckman Selection Model, Regression on the time-gap

	time in years		
	coefficient		standard error
research-transfer spin-off	-0.928	**	(0.457)
method-transfer spin-off[1)]	-0.721	**	(0.366)
team	-1.282	***	(0.357)
graduate	1.640	***	(0.428)
Motivations			
economic potential	-0.622	*	(0.355)
self-determined working	-1.593	***	(0.482)
income	-0.131		(0.307)
career	-0.404		(0.481)
demand	-0.024		(0.280)
Support			
courses	-1.228	**	(0.501)
infrastructure	-1.804	***	(0.669)
advisory	-0.256		(0.714)
contacts	0.309		(0.896)
colleagues	-2.851	***	(0.420)
Subjects/Disciplines[2)]			
nat & engin	-0.584		(0.623)
nat & business	-0.743		(0.896)
engin & business	2.482	***	(0.660)
other combination	0.039		(0.420)
Industry[3]			
cutting edge technology	0.932		(0.664)
high technology	1.736	**	(0.749)

Continued on next page...

Table 6 – Continued

other manufacturing	1.720		(1.126)
software	-1.774	***	(0.446)
knowledge intensive services	0.279		(0.313)
Constant	7.503	***	(0.702)
Selection equation			
continuous R & D	-0.101	***	(0.036)
contacts to science	-0.118	***	(0.045)
Year of establishment (Dummies)	included	**/***	
Constant	1.880	***	(0.140)
athrho	2.780	***	(0.148)
lnsigma	2.322	***	(0.023)
Observations	1810		
Censored observations	315		
Log pseudolikelihood	-5954.254		
χ^2	168.492		
Wald test of indep. eqns. (rho = 0): chi2(1) = 354.11 Prob > χ^2 = 0.0000			

Robust standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

1) reference category: competence spin-off, 2) reference category: single academic subject profile 3) reference category: technological services

Source: ZEW Spin-Off Survey 2001, author's calculations.

Appendix E

Table 7: Industry Classification: knowledge-intensive industries

NACE Rev.1	**Description**
Cutting Edge Technology Industries	
2330	Processing of nuclear fuel
2420	Manufacture of pesticides and other agro-chemical products
2441	Manufacture of basic pharmaceutical products
2461	Manufacture of explosives
2911	Manufacture of engines and turbines, except aircraft, vehicle and cycle engines
2960	Manufacture of weapons and ammunition
3002	Manufacture of computers and other information processing equipment
3162	Manufacture of other electrical equipment n.e.c.
3210	Manufacture of electronic valves and tubes and other electronic components
3220	Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy
3320	Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment
3330	Manufacture of industrial process control equipment
3530	Manufacture of aircraft and spacecraft
High Technology Industries	
2233	Reproduction of computer media
2411	Manufacture of industrial gases
2412	Manufacture of dyes and pigments
2413	Manufacture of other inorganic basic chemicals
2414	Manufacture of other organic basic chemicals
2417	Manufacture of synthetic rubber in primary forms
2430	Manufacture of paints, varnishes and similar coatings, printing ink and mastics
2442	Manufacture of pharmaceutical preparations
2462	Manufacture of glues and gelatines
2463	Manufacture of essential oils
2464	Manufacture of photographic chemical material
2466	Manufacture of other chemical products n.e.c.
2912	Manufacture of pumps and compressors
2913	Manufacture of taps and valves
2914	Manufacture of bearings, gears, gearing and driving elements
2931	Manufacture of agricultural tractors
2932	Manufacture of other agricultural and forestry machinery
2940	Manufacture of machine tools
2952	Manufacture of machinery for mining, quarrying and construction
2953	Manufacture of machinery for food, beverage and tobacco processing
2954	Manufacture of machinery for textile, apparel and leather production
2955	Manufacture of machinery for paper and paperboard production
2956	Manufacture of other special purpose machinery n.e.c.
3001	Manufacture of office machinery
3110	Manufacture of electric motors, generators and transformers
3140	Manufacture of accumulators, primary cells and primary batteries
3150	Manufacture of lighting equipment and electrical lamps
3230	Manufacture of television and radio receivers, sound or video recording or reproducing apparatus and associated goods
3310	Manufacture of medical and surgical equipment and orthopaedic appliances
3340	Manufacture of optical instruments and photographic equipment
3410	Manufacture of motor vehicles
3430	Manufacture of parts and accessories for motor vehicles and their engines
3520	Manufacture of railway and tramway locomotives and rolling stock
Technology-Intensive Services	
642	Telecommunications
72	Computer and related activities (722: Software)
731	Research and experimental development on natural sciences and engineering
742	Architectural and engineering activities and related technical consultancy
743	Technical testing and analysis Non-Technical Consulting Services
2224	Pre-press activities

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7133	Renting of office machinery and equipment, including computers
9211	Motion picture and video production
45114	Disaggregation of repositories
45120	Test drilling and boring
51146	Trade negotiation of office machines and software
51477	Wholesaling of precision and optical instruments and photographic equipment
51641	Wholesaling of office machines and software
52484	Retailing of precision and optical instruments and photographic equipment, computers and software
74201	Architectural and engineering activities and related technical consultancy
74704	Disinfection and pest control
74812	Photographic laboratories
74841	Fair and exhibition facilities
74844	Design studios
90009	Land reclamation and recultivation
91331	Education, science, research and culture organisations
92202	Production of radio and television programme
92324	Recording Studios
92325	Technical services for cultural and sustentative services
92522	Monument conservation
Knowledge-intensive services	
732	Research and experimental development on social sciences and humanities
7411	Legal activities
7412	Accounting, book-keeping and auditing activities; tax consultancy
7413	Market research and public opinion polling
7414	Business and management consultancy activities
744	Advertising
2214	Publishing of sound recordings
2215	Other publishing
6713	Activities auxiliary to financial intermediation n.e.c.
67203	Activities auxiliary to insurance and pension funding
74208	Business related technical consulting
74832	Translation activities
74842	Experts n.e.c.
74848	Supply of business related services n.e.c.
80422	Adult education
80424	Education a.n.g.
85144	Other self-employment in health care
92401	News agency activities
92521	Museums activities and art exhibitions

Remark: Differentiation according to the classification NACE Rev. 1 of the Statistical Office of the European Communities.
Source: Based on Egeln et al. (2003b), Grupp and Legler (2000)