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HOW NETWORKS AND SUPPORT MAY REMOVE BOTTLENECKS IN GROWTH OF UNIVERSITY SPIN-OFFS: (THE CASE OF DELFT UNIVERSITY OF TECHNOLOGY)*

Abstract: This chapter reports results of a study on the growth pattern of university spin-off firms. It includes an analysis of obstacles faced by these firms at different ages and of impacts of external factors on growth, *i.e.* support and knowledge networks. Delft University of Technology (The Netherlands) serves as an example of technical universities in Northwest Europe that have adopting a low selective model in the early years of the incubation strategy. This model implies a relatively slow growth of a large part of the spin-offs. It appears that obstacles to growth tend to be concerned with shortages in knowledge and skills in market issues and in management. In addition, market-related obstacles tend to be most resistant to disappear with age compared with other obstacles. Overall, the reduction rate of obstacles is 65.0% after six years, but it is 100% among highly innovative spin-offs. Networks enabling a certain diversity in knowledge that flows through the network tend to have a positive impact on growth. These are loose networks, weak networks, and networks of partners with a somewhat heterogeneous background and partners located at a relatively large distance from the spin-off firm. A positive influence on growth is also true for a mix of conventional support and added value support. The chapter briefly concludes with recommendations for an improved support to spin-offs and with some future research paths.

1. The move of universities towards the commercial sector

Until a few decades ago, universities in Europe and the US were more or less solid bastions of independent research, not directly engaged in real

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world applications. This traditional role of academic institutions is clearly reflected in various regional impact studies of universities where the main regional-economic effects of universities were estimated on the basis of multiplier studies related to expenditure patterns of universities' staff and students (see e.g. Armstrong, Taylor 2000). The commercial and industrial ('generative') effects, like the ones derived from knowledge valorization, were often overlooked. The reason why cities and regions were keen on establishing an academic institution in their territory was mainly stemming from the local prestige of an institute for higher education and advanced research.

In recent years, we have witnessed a much more direct involvement of academic institutions with commercialized knowledge acquisition and technology transfer. Universities are no longer an oasis in a rapidly changing environment; they follow a tidal movement in response to the request of society to offer not only societal relevance but also socio-economic and technological returns ('value for money'). The margins between the university systems and the commercial system sometimes have become fuzzy and sometimes very thin (Gibbons *et al.* 1994; Nowotny *et al,* 2001). At present, most US universities but universities in Western Europe have moved their mission and orientation towards the commercial and technology sector. The reasons for this are manifold:

- Lack of funding from the side of public bodies.
- Accountability to policy-making bodies and the public at large ('valorization').
- Insufficient usage of publicly financed research at universities for commercial applications in an age where competition in a global world becomes fierce ('technology transfer gap').
- Reduction in basic research in large corporate firms with the necessary consequence that publicly financed universities are pushed in this vacant positions.
- Far reaching changes in the research system itself (e.g. biomedical technology) where academic inventions incorporate a potentially high economic value that needs to be protected by IPR regulations and through subsequent licensing may be translated in monetary revenues.
- The rise of a knowledge-based society causing academic institutions to be much more strategic spearheads of accelerated economic growth, implying the rise of science-based clusters around universities, e.g. science park development (Monck *et al.* 1988).

Indeed, universities are often nowadays involved in the creation of spin-offs, *i.e.* new firms created as a result of an academic research environment with the aims to use new knowledge developed and owned by the university (or its staff) in a commercial setting. This rather new phenomenon which started perhaps modestly after World War II, grew in the early 1980s (Charles, Howells 1992) and has now fully entered the research policy of modern universities. Consequently, university policy is nowadays full of talks about invention disclosures, venturing, patenting and licensing (Shane 2004).

In the US, the passage of the Bayh-Dole Act (1980) has been of decisive importance. This law and its follow-on rights (1984) gave universities much more flexibility in licensing and commercializing federally founded research inventions, by stimulating the founding of spin-off companies serving to license and commercially develop these technological discoveries. The Act also stimulated SMEs to participate in publicly founded R&D initiatives. From a regional-economic development perspective, the university became potentially a very important player (Saxenian 1994).

There are several reasons why a strong orientation of a region (or nation) to an advanced or academic knowledge institution has many potential benefits. Shane (2004) distinguishes the following elements:

- University spin-offs create local economic development (through innovation, application of advanced technology and stimulation of an R&D climate).
- Spin-offs generate economic value (through financial assets), accelerate access to commercialized knowledge and the creation of a business climate.
- Spin-offs create employment in terms of skilled labor, but also indirect labor market effects.
- Spin-offs induce private investments in university technologies (through commercial initiatives such as patenting and licensing).
- Spin-offs call for new research initiatives (through a successful commercialization of an invention there will be a call for new inventions).
- Spin-offs are breeding ground for young talent (e.g. by offering internships and training facilities to students).

Three aspects are noteworthy in a local (regional) context. First, the development of a successful spin-off policy puts high demands on local and regional public authorities to orient regional development initiatives (e.g. infrastructure, incubators) towards promising R&D initiatives. Such a policy may be relatively general in aim by encompassing different high-technology areas, like micro-electronics, sensor technology, nanotechnology, informatics and computational science and biotechnology, or specifically focusing on specific area like biotechnology (e.g. Van Geenhuizen 2003). However, there are differences in incubation models leading to different contributions to regional economic growth. Secondly, it has become apparent that no single high-technology start-up can survive without networking to gain resources. Such firms critically depend on gaining the right resources in the right time (Reid, Garnsey 1998) and networks play a crucial role in this effort (Hoang, Antoncic 2003). This means that universities and their incubation organizations have an important responsibility in this respect, that is, in connecting their spin-offs with the relevant networks and in training them to develop these networks by themselves. Thirdly, it is now increasingly realized that university spin-off firms may be widely different in needs and bottlenecks at different ages, dependent on the entrepreneurs experience at the start, his/her ambitions, the field of activity (research or services) *etc.* (e.g. Druilhe, Garnsey 2004; Heirman, Clarysse 2004). In general, he difference between first-movers and followers has attracted attention.

This chapter examines the growth of university spin-offs (USO's) in a local setting by taking TU Delft in the Netherlands as a case study. The paper has a focus on external conditions of spin-offs, that is, networking and support for knowledge provided by the university or incubation organization. The chapter addresses two questions: (1) What are the characteristics of growth of TU Delft's spin-offs and which obstacles are faced by these spin-offs that hamper growth? (2) To what extent may knowledge networks and support, with their particular characteristics, provide solutions that remove obstacles to growth?

2. Triple Helix relations

University-industry-government relationships, also named the Triple Helix (e.g., Etzkovitz 2002; Leydesdorff 2003) can be seen as adaptive networks that change over time in response to various dynamics in the environment of the three actors. The networks fulfill three core functions, *i.e.* knowledge production, wealth generation and governance (control). One of the clearest changes over time is a blurring of the edges between the functions of each of the three actors. Thus, in Western Europe and North America, universities have become more entrepreneurial, whereas large companies have started knowledge production-based education in campuses hosting training in specific academic fields; and governments are increasingly engaged in enhancing the knowledge-based economy by improving conditions for entrepreneurial innovation (Etzkovitz 2002). As previously indicated, particularly the role of universities has changed in the past decade, with additional tasks in the entrepreneurial sphere, aside from the traditional ones in education and research. Also, universities have adopted more societal responsibilities, like in solving particular problems in the regional economy and society (e.g. Castells, Hall 1994; Charles 2003). There seems no end in the above changes, meaning a continued integration and hybridization of functions in the coming years, although the starting point and pace of changes may differ across countries (Viale, Etzkowitz 2005).

The attention given to support to university spin-offs and to their networking may be different per country but also within countries. Following Clarysse *et al.* (2005), we may distinguish between three generic policy models of incubation of university spin-offs.

a) Low selective model: a focus on self-employment of the entrepreneurs, leading to low to medium innovative and often service-oriented spin-offs.
b) Supportive model: a focus on growing spin-offs (higher level of innovation).
c) Incubator model: a focus on reaching financial gain from a future exit of spin-offs, e.g., through IPO or acquisition by a large company.

It seems that these models produce different types of spin-off firms in terms of innovativeness and growth patterns due to different criteria used "at the gate" of the incubation programs.

Partially parallel to the previous difference in incubation models, a distinction can be made between types of support provided to spin-offs. First, there is traditional support in terms of tangible assets, like room in an incubator building, secretarial services, and a loan (often without interest). Secondly, there is a trend to additionally provide added-value support, that is, support to increase the capabilities of the entrepreneur to produce a viable venture, like personal training and support in connecting with relevant networks, particularly concerning the market (niche). Before growth patterns will be examined in our case study of Delft's spin-offs, the attention turns briefly to theory on high-technology firms growth.

3. Theoretical ideas

It is increasingly realized that different needs for resources and different capabilities to access complementary resources in the environment lead to different growth paths and degrees of success of technology-based start-ups (Figure 1) (Reid, Garnsey 1998). A distinction can be made between early failure and steady growth, followed by different outcomes, like growth reinforcement, stability (eventually oscillation) and growth reversal. In specific high-technology areas, entrepreneurs need to be able to assess and satisfy their resource requirements as accurately as possible because they may gain a disproportional benefit if they meet the critical requirements at the right point in time. In contrast, lack of this capability can cause a stop of growth, either by entering a relatively steady phase or by falling back to a previous stage. Indeed, growth paths may be full of iterations. For example, failure in the resources generation phase may imply a returning to the mobilization of resources. The risk of falling-back or stagnation forces entrepreneurs to continuously evaluate their position and to deal with uncertainty.

A specific position among university spin-offs is hold by first-movers (or early entrants) in newly developed markets. The potential of these firms to acquire superior resources and capabilities is often addressed in the literature on first-mover advantages, but the outcomes of empirical research are ambiguous. Lieberman and Montgomery (1998) found the following superior resources: prime physical locations, a protected technology position (by patents), and monopoly in the market eventually by making a superior brand and establishing product specificities that cause "shifting costs" for customers. But the two authors equally stress that first-movers may miss the best resources because these are obscured by technological and market uncertainties. Likewise, they mention that first-movers may gain a head start in achieving key capabilities and competencies on the basis of learning curve advantages. Given these

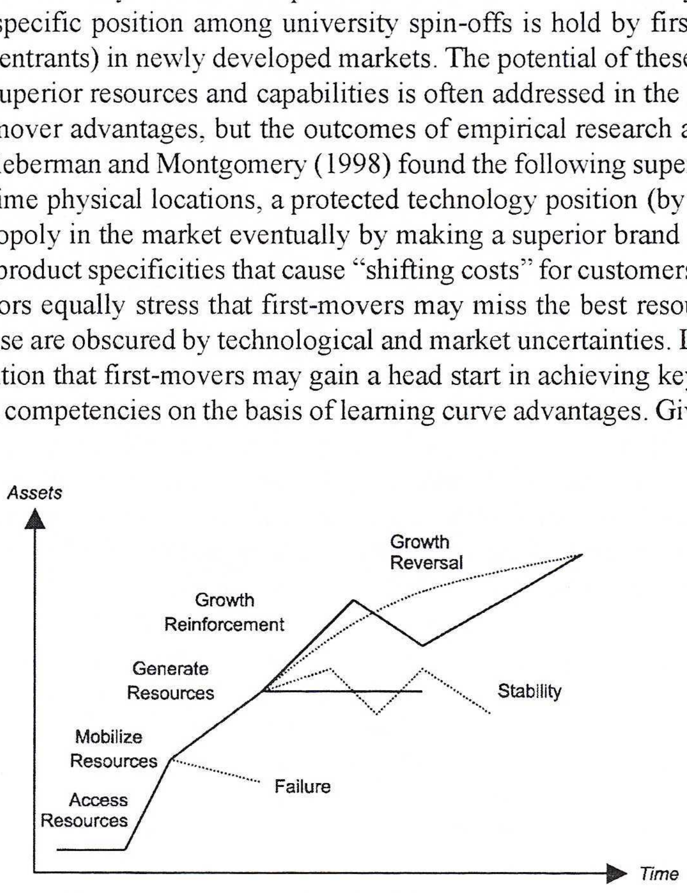

Figure 1. Potential growth paths of high-technology firms
Source: Reid, Garnsey (1998).

outcomes, it is difficult to draw conclusions on what obstacles can be expected in the first years among university spin-offs that are first-movers.

As previously indicated, employing network relations with various actors may enable start-ups to mobilize or generate resources otherwise not available. Knowledge is among the most important resources achieved in this way, not only concerning the specific technology application, but also concerning potential markets (niches), ways of marketing, strategy options, ways of achieving investment capital, *etc.* On the basis of a review of the literature, this study will focus on four socioeconomic aspects of knowledge networks that may influence growth: tightness, strength, heterogeneity and spatial proximity of network partners. Note that the literature is not conclusive on whether particular network characteristics contribute to growth. For example, some scholars adhere the idea that a strong tightness is beneficial for the transfer of complex and tacit knowledge, development of trust and comfort, and joint problem solving (Coleman 1990; Uzzi 1996). By contrast, others (e.g. Granovetter 1973) argue that loose networks cause benefits from diversity in knowledge flow and brokerage opportunities created by missing connections. In addition, Marsden (1987) shows that partners integrating different spheres of society facilitate more efficient actions than partners that are similar in background. In this latter respect, there is more or less consensus in the literature: the more heterogeneous the partners, the more variety in the resources (including knowledge) captured by spin-off companies and the better the performance.

With regard to spatial proximity in the networks, we may forward the following viewpoints. Local (regional) networks, according to proximity approaches, yield benefits of knowledge spillovers (avoided costs of knowledge exchange) and local learning through frequent interaction in person and high levels of trust (for example, Audretsch 1998; Keeble *et al.* 1999; Maskell, Malmberg 1999). Following Camagni (1991), a close proximity between spin-offs and network partners supports the gaining of new knowledge (reduction of uncertainty) thereby enhancing growth of spin-offs. On the other hand, local networks may also produce the above-indicated disadvantage of strong ties preventing new knowledge to be recognized and absorbed by young spin-off firms.

Regarding the two different types of support (conventional support and value-added support combined with conventional support) it is expected in this study that spin-offs experiencing a balanced mix of conventional support and value added support grow quicker compared with spin-offs that experience merely conventional support or a poor mix. The next sections will explore and test the above ideas and assumptions.

4. How TU Delft Spin-offs grow

4.1. Introduction to the case study

Delft University of Technology is in Delft, a small town (about 95.000 inhabitants) in the densely populated Western part of the Netherlands. It represents a category of technical universities in Western Europe that started involvement in the development of new technology-based firms relatively late. Delft University of Technology adopted a first policy to support academic entrepreneurship in 1998. Prior to this year, some support was given but this did not happen through an explicit policy. By contrast, the initiative in 1998 was built on the national program 'Technostarters' and provided a set of support measures from which academic entrepreneurs could select, dependent upon their personal needs, such as a loan (without interest) up to a maximum of €16,800, use of accommodation at the faculty and, if available, coaching by faculty members. The program did not provide room in an incubator building. Rather, the spin-offs were dispersed in faculty buildings (laboratories) and in various business buildings hosting start-ups in the city of Delft. To strengthen the initiative in 2005, the university established a close collaboration with the Municipality of Delft and set up an incubator program named YES!Delft. This new program encompasses a more comprehensive set of support measures, including room in an incubator building and additional value added support.

Overall, the early programs may be qualified as "low-selective" (Clarysse *et al.* 2005) meaning that the access criteria are not strong in terms of level of innovativeness. This allowed spin-offs to enter the incubation program that are less ambitious, e.g. aim at self-employment, alongside highly ambitious and innovative spin-offs. Since 2005, however, rules to join the incubation program are more tight in terms of level of innovativeness.

With regard to the number of spin-offs established in the past years, the incubation program of Delft University of Technology can be seen as a moderate success, compared with other technical universities in the Netherlands and the agricultural (life sciences) University of Wageningen[1]. So far measured, the University of Twente in Enschede turns out to be most productive of all univer-

[1] Measuring and comparing the number of spin-offs between universities is a difficult matter. Definitions of spin-offs may be somewhat different (e.g. including or excluding start-ups established by alumni some years after graduation and first job). Also a complete coverage is impossible to achieve because there are no standard statistics or monitoring systems.

sities, as witnessed by a number of 7.9 spin-offs per 1000 fte in 1999-2001 (2.1 spin-offs for Delft University of Technology) (MEA 2003a, 2003b). Spin-off productivity of universities, however, needs to be seen in a regional-economic policy perspective to some extent. The University of Twente was established in the 1960s just as a part of a national and European policy to support the restructuring of the regional economy (Twente), following the collapse of the textile industry. In this vein, this university started to develop an incubation policy already since the late 1970s. Different from Twente, Delft is in the economic core area of the Randstad with relatively large cities adjacent (The Hague) or at a close distance (Rotterdam, with its own university and incubation program).

The population of spin-offs of TU Delft in this study could be delineated using three criteria, *i.e.* located in Delft or surrounding area, aged not older than 10 years, and having used at least one support measure from TU Delft. All firms in this population have been approached, leading to a response rate of 67% (51 valid cases). Data were collected using a semi-structured questionnaire in face-to-face interviews with entrepreneurs (lasting 1.5 hour on average). The focus of the interviews was particularly on identifying obstacles to growth and the extent in which growth is connected with socioeconomic aspects of knowledge networks and various combinations of types of support.

4.2. Growth patterns and obstacles to growth

The growth rate of spin-off companies of TU Delft can be qualified as relatively modest over the past years (1996-2005) (Table 1). About 30% of the spin-offs face a very small job growth or no growth at all (less than 0.5 jobs on average per year) while only 25% face a growth of more than 1.5 jobs on average per year. The average growth rate among all spin-offs is 1.1 and varies between 0.0 and 6.0 jobs per year.

Table 1

Job growth of TU Delft's spin-offs (1996-2005)

Average annual job growth (fte)[a]	Number of spin offs	Percentage share
< 0.5	16	31.4
0.5 – 1.0	12	23.5
1.00 – 1.5	10	19.6
> 1.5	13	25.5

a) full-time equivalent.

Source: Author's survey (Tables 1-3, 6-7).

Table 2

Success stories of Delft spin-offs

Firms and year of establishment	Total job growth (fte)	Product/markets
A (1998)	47 (1998-2006)	Activity: in ICT sector; Enterprise Content Management for development of Internet and Intranet Portals of large customers
		Newness of product/services: 20% of turnover derived from incrementally improved or radically new products
		Market: Public sector organizations (ministries, municipalities), medical organizations
B (1997)	18 (1997-2006)	Activity: in ICT sector; customized software to increase efficiency of specific tasks. Development in close cooperation with network partners
		Newness of product/services: 60-70% of turnover derived from incrementally improved or radically new products
		Market: diverse (e.g. municipalities for online archives and companies for mobile time-registration)
C (1995)	50 (1995-2006)	Activity: in new materials (composites); development, production and engineering services of light weight components and systems, on customer specification
		Newness of product/services: 100% of turnover derived from incrementally improved or radically new products
		Market: defence and aerospace industry, oil & gas and marine market

Although growth of spin-off companies in Delft is on average relatively modest, it is relevant to mention a couple of *success stories* (Table 2). The firms selected are relatively old ones (8-11 years). Two are active in the ICT sector as tool/software developers, of which one is highly innovative (but also relatively slow growing). One firm is in material science (composites) and development. A is most successful in terms of growth. B and C stand out in innovative character of their product/services.

In a self-evaluation during the interviews, all entrepreneurs could forward various obstacles that have hindered growth (Table 3). It appears that most obstacles are concerned with shortages in knowledge and skills in market issues and management. It is not surprising that lack of marketing and sales skills are the main obstacles (17 and 16% of all obstacles), since most spin-offs evolve from an initial idea in a non-commercial setting to a profit-generating company in a competitive setting, situations in which completely different resources (knowledge and skills) are required. Similarly, the importance of the third main obstacle, difficulty in dealing with uncertainty (14%) can be understood by taking the shifting context of the entrepreneurs into account. At technical universities, students and staff are trained to reduce uncertainty in experiments and measurement as much as possible, whereas as entrepreneurs they are facing a manifold uncertainty, residing in the technology, development of the market, finding adequate investment capital, *etc.* With regard to problems of market demand (11%) some spin-offs turn out to be subject to a vicious circle in that they are not able to acquire a large customer, just because they had none before. This situation is generally known as the problem of market credibility (Soetanto, Van Geenhuizen 2006).

Note that financial obstacles occur less frequently than market- and management obstacles (5 to 7% of all obstacles). This may be attributed to a combination of factors. Very often, at the start, family, friends and 'fools' provide start capital (for example, Roberts 1991) whereas later on, problems arise in attracting venture capital or a regular loan from banks. However, a substantial number of TU Delfts' spin-offs adopt or shift to a business model of self-financing by adding routine research or trade to their research or development activities (Van Geenhuizen, Soetanto 2004). However, self-financing solves

Table 3

Problematic obstacles as perceived by entrepreneurs

Obstacles	Specification	Total	%	Rank
Market knowledge/skills	Lack of marketing knowledge	26	17.2	1
	Lack of sales skills	24	15.9	2
	Lack of forecasting capability about future markets	20	13.3	4
Management capability	Difficulty in dealing with uncertainty	21	13.9	3
	Management overload	15	9.9	6
Market	Lack of market demand	16	10.6	5
Financial	Lack of investment capital	11	7.3	7
	Lack of cash flow	7	4.6	8
Accommodation/Facilities	Lack of adequate accommodation	5	3.3	9
	Lack of research and testing facilities	4	2.7	10
Other obstacles	Government bureaucracy	2	1.3	11

financial problems but at the same time may introduce another, probably more important problem, that is, a decrease of time and effort spent on the innovative product (process), potentially causing a lagging behind competitors.

4.3. Obstacles at different ages

In a previous study, dealing with obstacles among Delft's spin-offs (Soetanto, Van Geenhuizen 2006) we examined how these firms solve or prevent the occurrence of obstacles during their early years. In measuring occurrence of obstacles over different ages we made use of the so-called "obstacle incidence rate" (OIR), derived by dividing the total number of obstacle per age-category (class or year) by the number of spin-offs in that category[2]. Accordingly, an obstacle incidence rate of 1.00 for a particular age (class) means that on average a spin-off firm is facing one serious obstacle to growth. It appears that in the youngest age-class (younger than 3 years) different obstacles tend to arise simultaneously, such as problems with finance, market-related and management-related problems, and to a smaller extent, accommodation and infrastructure problems (Table 4). In the second age-class (3-5 years), some of these obstacles still exist but their number has clearly decreased. There is a decline in the average number of obstacles per firm by 26.1% between the first and second age-class.

Next, particular problems are almost solved in the second and third age-class, *i.e.* concerning physical infrastructure and financial problems, while others tend to remain somewhat resistant (market- and management-related problems). The reduction of the number of average obstacles between the second and third age-class amounts to 45.3%. Overall, the obstacle incidence rate of the three age-classes (3.29, 2.43 and 1.33, respectively) and the outcomes of the t-tests (Table 4) suggest a significant decrease of obstacles between the first and the third age-class only (by 59.6%), indicating a slow but sure increase of the capability of the spin-offs to solve (or prevent) problems.

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[2] The so-called obstacle incidence rate (OIR) is calculated by dividing the total number of obstacle per age-category (class or year) by the number of spin-offs in that category, as follows:

$$\textit{Obstacle incidence rate (OIR)} = \frac{\sum_{i=0}^{t} O_i}{\sum_{i=0}^{n} X_i}$$

O = number of obstacles per age (class)
X = number of spin-offs in the age (class)
t = age category or year
n = 0,1,2, ...

Table 4

Current obstacles per age-class (cross-section)

Obstacles	< 3 years (t)	3-5 years (t+1)	≥ 6 years (t+2)
Market-related	15	12	7
Finance	17	9	3
Management	13	11	5
Physical (e.g. accommodation)	8	1	0
Remaining (e.g. regulation)	3	1	1
Total nr of obstacles	56	34	16
Total nr of spin-offs	17	14	12
Obstacle incidence rate (*OIR*)	3.29	2.43	1.33
t-test (t) and (t+1)		0.245	
t-test (t+1) and (t+2)			0.225
t-test (t) and (t+2)			0.023*

* Significant at the 0.05 level.
Source: Soetanto, Van Geenhuizen (2006) (Tables 4, 5).

In order to identify trends in the capability of spin-offs to fight (prevent or remove) obstacles, the "obstacle reduction rate" (*ORR*) was introduced in this study, measured by dividing the difference in obstacle incidence rate between two age-classes with the obstacle incident rate of the reference age-class (OIR_t)[3]. The obstacle reduction rate over the three age-classes amounts to:

- 34.1% for market-related obstacles (OIR_t is 0.88 and OIR_{t+2} is 0.58)
- 75.0% for financial obstacles (OIR_t is 1.00 and OIR_{t+2} is 0.25)
- 44.7% for management obstacles (OIR_t is 0.76 and OIR_{t+2} is 0.42).

The reduction rates show that market-related obstacles tend to be quite resistant to disappear with age compared with other obstacles over all three age-categories. By contrast, financial obstacles tend to be solved quite drasti-

[3] The so-called obstacle reduction rate (*ORR*) is measured by dividing the difference of *OIR* between two age-classes with the reference *OIR* (OIR_t), as follows:

$$\textit{Obstacle reduction rate } (ORR) = \frac{OIR_{t+n} - OIR_t}{OIR_t} \times 100\%$$

OIR_t = obstacle incidence rate in the t age (class)
OIR_{t+n} = obstacle incidence rate in the $t+n$ age (class)
t = age (class)
n = 0,1,2, ...

cally. This pattern contradicts other studies that indicate that financial needs just increase or culminate after a few years of existence of the spin-offs when their product (service) has proven to be viable and (small) series production facilities are needed, or when additional R&D is necessary following the first seed-stage, like in research-intensive medical biotechnology (Van Geenhuizen 2003; Powell *et al.* 2002). As previously indicated, Delft spin-offs tend to solve financial problems partially by means of self-financing. A majority (72.1%) undertakes some routine work in the own firm or has part-time jobs elsewhere to enable self-financing (Van Geenhuizen, Soetanto 2004). An alternative explanation may be that older spin-offs facing financial problems collapse more frequently than older spin-offs facing other problems (thus, are excluded from the survey).

We now move to a *longitudinal* perspective and focus on obstacles that spin-offs have been facing during their lifetime, using retrospection by the entrepreneurs covering seven years at maximum (year 0 to year 6). Although the impact of a memory gap may have caused some bias in the longitudinal data, we may assume a sufficient reliability of the longitudinal results if these broadly confirm patterns found on the basis of cross-sectional data. This is indeed true (Soetanto, Van Geenhuizen 2006). Table 5 indicates that obstacles tend to decline substantially at age two and at later ages (five and six). Overall, the reduction rate is 65.0% meaning that in six years time there is a significant decrease of obstacles to growth. Note that the ability to prevent and/or solve obstacles tends to fall back at the age of three and four which may point to a somewhat problematic situation. In this sense, age three and four may be qualified as critical.

Table 5

Obstacles per age (longitudinal)

Age	Obstacle reduction rate all USO's (ORR)	Obstacle reduction highly innovative USO's (ORR)
1	-4.6	+10.0
2	-19.5	-22.6
3	-11.0	-23.1
4	-8.6	-13.3
5	-28.4	-56.2
6	-21.7	-100.0
Overall	-65.0	-100.0

By focusing on highly innovative spin-offs, it appears that the number of obstacles tends to increase right after the start. This is followed by a decrease at higher rates than among all university spin-offs, particularly at age three (-23.1 versus –11.0) and age five (-56.2 versus –28.4). At age six, obstacles among highly innovative spin-offs tend to be fully solved. It seems that, contrary to the entire sample of spin-offs, the first year is the most problematic one for highly innovative spin-offs.

5. Role of Networks and of support

This section examines the role of external factors in growth of TU Delft's spin-offs. Although the data prevent to establish an accurate connection between obstacles at different ages and participation in networks and kind of support received at these ages, these allow to estimate the influence of networks and support on average growth during the lifetime of the spin-offs. The model used is based on Ordinary Least Square (OLS) regression analysis. The way the variables are measured is given in the Appendix. Descriptive statistics are shown in Table 6. Two models are estimated[4]. Model 1 deals with the

Table 6

Descriptive statistics

	Mean	S.D.
Dependent variable		
Job growth (1996-2005)	1.1 (fte)	1.0
Independent variables		
Characteristics of knowledge networks (2005)		
Tightness of relationships	0.27	0.20
Strength of relationships	8.13	4.36
Homogeneity in partners' social background	0.58	0.13
Spatial proximity of partners	20.01 (min. by car)	8.05
Type of support		
Rank of mix of support	2.58	0.80

N (spin-offs): 51.

[4] To check for multicollinearity, the so-called variance inflation factor (VIF) was used. Large VIFs are an indication for the presence of multicollinearity. In the regression analysis, the VIFs found in the estimates ranged from 1.24 to 1.58, meaning that no multicollinearity problems occurred.

Table 7

Results of the regression analysis

Independent variables	Model 1	Model 2
	β	β
Socioeconomic network aspects		
Tightness of relationships	-0.321**	-0.299**
Strength of relationships	-0.329*	-0.196*
Homogeneity in partners' social background	-0.269**	-0.258*
Spatial distance of partners	0.442**	0.405**
Support		
Mixed conventional and added value support		0.190*
F	22.64	20.59
Significance of F (Prob<F)	0.00	0.00
R^2	0.7155	0.7462
Adjusted R^2	0.6839	0.7100

*p < 0.10, **p <0.05
N (spin-offs): 51

influence of different socioeconomic aspects of knowledge networks, whereas Model 2 deals with the influence of these network aspects plus a single variable indicating the kind of support enjoyed by the spin-offs.

It appears that the beta-coefficients of all variables concerning the network characteristics and the mix of support are significant in the two models, in Model 1 mostly at the 0.05 level (Table 7). Two beta coefficients are significant at the 0.05 level in both models: tightness of the relationships and spatial distance to network partners. The outcomes of Model 1 say that 72% of the variation in growth can be explained by different network characteristics. By adding the variable of mix of support, this increases to 75%. By examining the *signs* of the beta coefficients, the following becomes clear. All three network characteristics that potentially exclude diversity in knowledge networks, like relations that are more tight, stronger and more homogeneous, all tend to negatively influence the growth of spin-offs. With regard to spatial proximity, the results point to a positive influence of relatively large distances between spin-offs and their network partners. This result contradicts the idea of benefits from local proximity, but tend to confirm ideas of a negative influence of tightness based on a close location (like the negative influence of a strong tightness in general). With regard to the kind of support, the *sign* of the beta coefficient indicates that combinations with higher shares of value added support (not merely or mostly conventional support) tend to enhance growth.

This study focused on how spin-off firms of TU Delft (the Netherlands) have grown over time, which obstacles to growth they have encountered and which type of knowledge networks and support may have contributed to a positive growth. Despite a small potential bias (due to non-response) the sample seems sufficiently representative for technical universities in North-West Europe that have adopted a "low selective" incubation strategy, meaning that a substantial number of spin-offs established for self-employment or independence reasons could enter the incubation program. Accordingly, the growth rate of spin-off firms of TU Delft has been relatively modest over the past years (1996-2005). About 30% of them face a very small job growth or no growth at all (less than 0.5 jobs on average per year) while 25% face a growth of more than 1.5 jobs on average per year. This study could also identify which obstacles played a role in hampering growth. Most obstacles tend to be concerned with shortages in knowledge and skills in market issues and management, like lack of marketing and sales skills, and with general business uncertainty. In addition, market-related obstacles tend to be most resistant to disappear with age compared with other obstacles. Overall, the reduction rate of obstacles is 65.0%, meaning that in six years time there is a significant decrease of obstacles that hinder growth. Among highly innovative spin-offs, by contrast, this is 100%. Critical ages – at which the problem-preventing or -solving capacity decreases – seem to be age three and four for all spin-offs and age one for highly innovative spin-offs.

Next part of the study dealt with an analysis of external factors – networks and support – that potentially contribute to solving and preventing obstacles, and ultimately contribute to growth of the spin-offs. The results indicate that knowledge networks introducing a certain amount of diversity tend to have a positive impact on growth. These are loose networks, weak networks, networks of partners with a certain heterogeneity in background, and partners located at a relatively large distance. The same influence is true for a mix of conventional support and added value support (including a relatively high share of the latter). However, it was beyond the borders of this study to identify whether the diversity characteristics lead to an optimum and when (under which values) that is reached. Non-linearity may play a role, meaning that looseness, weakness and partner heterogeneity contribute to growth to a certain extent but that after an optimum there is no change or even a negative influence. This could be an interesting path in future modeling of growth.

In addition, the study revealed a dominance and resistance over time of market-related problems connected with a lack of knowledge and skills. This situation implies that support measures preferably focus on a better networking with the market and with training of entrepreneurs to improve such networking. Note that markets (niches) may be substantially different between spin-offs and may also be different for one and the same spin-off, calling for a more personal approach in such training. Also, highly innovative spin-offs need to be supported in a different way compared with other spin-offs. Highly innovative spin-offs need support right at the start while other spin-offs need support at age three and four, or somewhat earlier in order to prevent the emergence of obstacles at these ages. Networking concerning potential markets is preferably relatively open, *i.e.* deploying loose and weak relations and a certain heterogeneity in the networks, including partners outside the local community. In addition, conventional support needs to be extended with value added support, particularly personal training of entrepreneurs to identify markets and to achieve skills to present themselves and negotiate convincingly with market parties.

This study attempted to identify the occurrence of hurdles in the early years of spin-off firms using a retrospective analysis. This type of research potentially suffers from memory gap and from excluding problematic spin-offs (not survived and therefore not in the sample). A potential bias in the results due to these circumstances may be prevented in a panel study. In such a study, spin-offs are monitored from their start and each major event (including the rise of obstacles) is registered when they occur, including the causal context at that time.

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Appendix 1

Variables and measurement

Variables	Measurement
Job growth	Average annual growth of jobs in 1996-2005 (full-time equivalent).
Tightness of relationships	Number of existing relationships divided by the number of potential relationships. The latter is calculated as the maximum number of relationships if all partners in the network are connected (McEvily, Zaheer 1999; Rowley *et al* 2000). The value is between 0 and 1, with a low value indicating a loose network and a high values indicating a tight network.
Strength of relationships	A mixed indicator calculated on the basis of the average frequency of interaction with partners and the average number of years that the relationship has lasted (a). Following Granovetter (1973) and Marsden and Campbel (1984), the variable is the added sum. Low values indicate weak relationships and high values indicate strong relationships.
Homogeneity of network partners	Scores on a heterogeneity index. The scores are calculated on the basis of the square of the number of partners with a similar social background divided by the total number of partners, basically like in Scholten (2006). We used three different backgrounds, *i.e.* university, large company and small company. A high value indicates a dominance of a similar background (homogeneous) and a low value indicates a dominance of partners from a diverse background (heterogeneous).
Spatial proximity	Average travel time to partners by car (face-to-face meetings). A low value indicates close proximity whereas a high value indicates a large distance.
Mix of support	A rank variable (1-4). This variable is calculated as the level of mix of conventional (room, standard services and loan) and added-value support (e.g. customized training of entrepreneurs), with rank 1 representing merely conventional support and rank 4 representing conventional support and 60% or more value added support.

(a) Granovetter (1973) suggests that the strength of a relationship is a combination of characteristics, like time spent in the relation, emotional intensity, and intimacy, *etc.* We were not able to measure the more emotional aspects (intensity and intimacy) directly but used proxies (frequency of interaction and duration of the relationship).