J Technol Transf (2013) 38:235–250
DOI 10.1007/s10961-012-9251-1

The university's unknown knowledge: tacit knowledge, technology transfer and university spin-offs findings from an empirical study based on the theory of knowledge

Fritjof Karnani

Published online: 20 March 2012

Abstract The assumption that research findings provide the basis for spin-off projects at universities has been found up to now in literature and the practice. Supported by the theory of knowledge, the empirical study presented here shows that this idea is too limited. Only 45 % of spin-offs use codified research findings from the university, while 55 % use tacit knowledge that was acquired at the university. These spin-offs use knowledge beyond research findings, starting companies in the shadow of publications by academic institutions and drawing from the realm of tacit knowledge at universities. Tacit start-up knowledge is present in all scientific disciplines of universities; even the exploitation- and patent-oriented engineering sciences account for almost half of the start-ups. Start-ups based on tacit knowledge lead to both technology-oriented and service companies. They also do not differ from codified knowledge-based start-ups in the number of jobs that they create. The discovery of the tacit knowledge spin-offs as a phenomenon has an entire series of implications for the practice and research. The tacit start-up potential was not considered previously in the university promotion instruments and start-up consultancies. Furthermore, we can assume that tacit knowledge-based start-ups are only an initial indication of the innovation potential within the tacit realm of knowledge for universities and research institutes.

Keywords Technology transfer · University spin offs · Tacit knowledge · Theory of knowledge

JEL Classification M13 · O31 · O32

F. Karnani (✉)
Entrepreneurship and Management, Hochschule Osnabrueck, Am Wall Süd 16, 49808 Lingen, Germany
e-mail: f.karnani@hs-osnabrueck.de; karnani@gmlg.de

F. Karnani
Institut für Unternehmensentwicklung/Institute of Corporate Development,
Leuphana Universität Lüneburg, Scharnhorststraße 1, 21335 Lüneburg, Germany

1 Introduction

Spin-off activities at universities and research institutes are subject to an ever-growing number of publications as they increasingly move into the focus of economic development and also increasingly gain importance—as part of the knowledge and technology transfer—for universities.[1]

However, the discussion about spin-offs from public research is generally limited to the case that results of research projects are brought to the market by scientists within the scope of a start-up. This study's starting point is the question of whether this perception does justice to the start-up activities and the start-up potential of public research.

Those who work in start-up consulting at a university quickly encounter start-ups beyond the research findings. For example, doctoral students may develop a new measurement instrument out of necessity because the equipment available on the market does not meet their requirements; in the process, they incidentally and unintentionally create a promising product innovation. An algorithm developed in an economic institute may suddenly prove its effectiveness in a completely different area of application. Both are typical examples from consulting practice that can be found in a similar form at many universities. From the perspective of institutes and scientists, these innovations do not represent research findings but just by-products on the path to scientific discovery. What role do these process and product innovations that have been developed as *by-products* play—on the path of achieving a research goal—for spin-off activities at universities? Are these individual special cases or even just a myth comparable with the classic (and false!) legend of the Teflon pan as a by-product of space travel?

The examination of this question is appropriately linked to the source of all innovation: the creation of knowledge.

2 State of research and theoretical concept

The central criterion for classifying a company as a spin-off of a university or research institution is the *transfer effect*, which means the spin-off company's exploitation of the knowledge created at the university. This classification directs the focus to the knowledge-transfer process with which the scientific findings of spin-offs are transferred into the economic realm. Consequently, it is sensible to use knowledge itself—its origin—as the object of observation and examine the spin-off process from the perspective of knowledge theory when considering technology- and knowledge-based start-up companies from universities and research institutes.

The current study deals with those sub-sections of knowledge that are described as t*acit*, *non-coded* or *hidden knowledge* and have attracted little attention in spin-off research up to now. The concept of *tacit knowledge* dates back to Polanyi (1966, 1985), who on the one hand opened up new horizons for a new and different approach about the general types of knowledge with the statement that "we can know more than we can tell" (1966); at the same time, he established a new theory about the creation of knowledge, especially since it also applied to the academic context. Polanyi differentiates between explicit and tacit

[1] See Rothaermel et al. (2007) and Djokovic and Souitaris (2008) for a detailed literature analysis of the research on university entrepreneurships.

Druilhe and Garnsey (2004) explore typologies of spin-offs, using a Penrosean conceptualization of entrepreneurial activity.

knowledge. Both types of knowledge are directly linked according to Polanyi, and tacit knowledge is an indispensible component of explicit knowledge (Polanyi 1966, 1985).

Nelson and Winter (1982) view tacit knowledge as closely associated with skills and knowledge from experience. Sternberg et al. (2000, 1995) consider tacit knowledge as *practical intelligence* and action-oriented. Wagner (1987) places tacit knowledge in the area of know-how. Sternberg also refers to the context-dependence of tacit knowledge: "It is a knowledge typically acquired on the job or in the situation where it is used" (Sternberg 1994).

Nonaka and Takeuchi (1997) builds on Polanyi's work and determines that tacit knowledge includes both technical and cognitive elements. The technical aspect of tacit knowledge extends to concrete know-how while the cognitive elements contain mental models with which people find their way in the world. Leonard and Insch (2005) expand on Nonaka's two-dimensional approach by adding a third element, the social dimension, to the multi-dimensional model of tacit knowledge. Above all, the third dimension includes the area of social interaction and originates from the observation that people do not act in a vacuum but within social contexts (Leonard and Insch 2005).

When looking at tacit knowledge from a resource-oriented perspective, the externalisation gains a special significance. Nonaka and Takeuchi (1997) describe the course of externalisation as a process of articulating tacit knowledge in explicit concepts. In the various approaches to the understanding and nature of tacit knowledge that are described, there is agreement that sub-sections of tacit knowledge are closely tied to the experiences and skills of a particular person, which evade the attempt to verbalise and externalise them. But even if it is not possible to externalize the total realm of tacit knowledge, this does not exclude the fact that it is possible to explicitly utilize partial aspects of tacit experiences (Ambrosini and Bowman 2001) and to derive economic value from them (Güldenberg and Helting 2004). Agrawal (2006) refers to tacit knowledge as knowledge that is potentially codifiable as latent knowledge. The current study is guided by the idea that this precisely describes what is implemented by a multitude of spin-offs: The externalisation of economically relevant knowledge that was generated at a university. However, this knowledge remained there within the tacit realm of knowledge. It is externalised by the founders and exploited economically in the form of a start-up.

In order to facilitate a study on the significance of tacit knowledge in the spin-off process, we must first apply the concept of tacit knowledge to the situation of universities. Scientific discoveries are considered the typical example of codified knowledge. There is no doubt that published research findings constitute codified knowledge and an ideal type of explicit, formulated or even available knowledge. Consequently, it stands to reason that spin-offs solely rely on codified knowledge. Nevertheless, a closer examination reveals that tacit realms of knowledge also exist in research institutes.

A core task of a scientific institution is the codification of results with the goal of scientific publication. At the same time, this is one of the most important qualification criteria against which the institution must allow itself to be measured. Whatever exists in the shadow of research findings, which means that it has no relevance for publication, is located outside the strictly formalised codification process. Whether knowledge solely remains in the realm of tacit knowledge because it has no relevance for scientific publication depends on the culture and organisational structure of a scientific institution.

It is inevitable that the measures of value at research institutes are primarily based on scientific factors. Economic valuation standards only play—if at all—a subordinated role. As a consequence, a development that has a high potential for innovation but simultaneously little or no scientific value will possibly remain in its undiscovered shadow existence. Start-ups based on tacit knowledge draw from precisely this shadow area. Only the tacit realm of knowledge's *publication-relevant* areas are systematically externalised. Economically interesting findings without *publication relevan*ce often remain within the tacit scope.

Pearson et al. (1993) point out that knowledge remains within the realm of tacit knowledge at research institutes solely because it is not considered valuable enough to be transferred. For example, some tacit knowledge develops in research laboratory work during the troubleshooting process (Barley and Bechky 1994; Gorman 2002). Agrawal (2006) recommits to failed experiments, stating that a lot of unsuccessful experiments are conducted in science and that the scientist learns from all of them, but only publishes information about the final experiment.

Gorman (2002) develops a framework to better understand tacit knowledge transfer. He classifies knowledge into four types: declarative (knowing what), procedural (knowing how), judgment (knowing when) and wisdom (knowing why). But to get an impression of the overall depth and breadth of tacit knowledge in research, we have to go beyond the published journal articles. "Although many studies continue to portray scientific work operation within a highly and formalized set of codes and framework, evidence from the pharmaceutical industry (…) suggests that intuition, serendipity and craft skills—all based on tacit quantities—still play an important role in the process of scientific discovery" (Howells 1996).

Previous empirical work identifies the significance of tacit knowledge in the transfer process. Especially in biotechnology tacit knowledge received a lot of attentions from scholars (Pisano et al. 1988). The agglomerations of start-ups near universities are partly explained by the need to transfer tacit knowledge between university-based scientists and biotechnology firms (Audretsch and Stephan 1996; Zucker et al. 1998a). It is implied that not all relevant information is codified in publications. Hence, the missing tacit knowledge must be obtained by face-to-face contact. Consequently, social contacts and informal communications became an important part in the process of commercializing universities knowledge (Audretsch and Stephan 1996). This finding is supported by Zucker et al. (1994, 1998b, 2002), Zucker and Darby (2001), stating that this stream of study has focused on star scientists and their links to entrepreneurial biotech firms. These university-based star scientists hold relevant tacit knowledge and this human capital has to be transferred.

Even in the realm of highly codified university knowledge, scholars detect tacit components. The empirical work of Agrawal (2001) examines the importance of tacit knowledge in the universities-industries-lizent Agreements. By analyzing 124 license agreements from MIT, Agrawal reports that the geographic distance, measured in miles from MIT, has a negative effect on the commercial success of the licensee. However, direct interactions between the university inventor and company scientist, measured in hours, had a positive effect on the license agreement. These findings suggest that even if a university invention is highly codified in terms of a pending patent, some knowledge that is relevant for commercialization is still tacit and has to be made available by human interactions.

Then there is the question of what if the invention is associated with high levels of tacit knowledge? The relationship between university tacit knowledge and spin-offs was illustrated by Lowe (2006) in a theoretical model. Under the assumption of his model, inventions with a high tacit level will always be developed via inventor-founded start-up firms. This is the case because the inventor holds the critical asset for successful development and can extract full monopoly profits related to an invention.

3 Formulation of hypotheses

3.1 Significance of tacit knowledge in the spin-off process

The available empirical findings on the spin-off process allow, at most, an indirect deduction regarding the significance of tacit knowledge. In a very comprehensive empirical study, Spielkamp et al. (2004) differentiates spin-offs from universities and research institutes into transfer spin-offs and competence spin-offs. In the case of transfer spin-offs, these are spin-offs from universities or research institutes where new research findings were indispensible for the start-up. On the other hand, the methods and special skills that the founder of the scientific institution has acquired are indispensible for the start-up of competence spin-offs (Spielkamp et al. 2004). For the second half of the 1990s, the study concludes that an annual average of 6,800 spin-offs from public research institutes in Germany can be divided into 2,600 (38 %) for the group of transfer spin-offs and 4,200 (62 %) for the group of competence spin-offs.

Competence spin-offs are the dominant form of start-up at universities and research institutes, which means the companies that were established beyond the scope of the formalised research findings (Spielkamp et al. 2004). There is no doubt that the group of transfer spin-offs uses codified knowledge as the basis for the start-up project. On the other hand, there is an assumption that a large portion of spin-offs from the group of competence spin-offs realise their start-up on the foundation of tacit knowledge. Consideration of this information leads to the following hypothesis:

H 1 Spin-offs can be categorised in two general groups according to the knowledge they employ: One group primarily uses codified knowledge while the other group predominantly uses the tacit knowledge of the parent institute.

3.2 Tacit knowledge relevant to spin-off in the various scientific disciplines

The assumption is that the portion of spin-offs that were established on the basis of tacit knowledge is not evenly distributed across various academic disciplines. In fact, it is assumed that many start-ups relying on tacit knowledge originate from the humanities, social and cultural studies. These research findings from engineering and natural sciences are considered relevant for exploitation to a higher degree per se than the research findings of the humanities, social and cultural studies. In addition, there is a difference in the exploitation cultures of the various academic disciplines. A good example of this is the term of *technology transfer*, which is often used as a synonymy for *knowledge transfer*—also in the non-technical sense—from the university to the business world. Last but not least, the various academic disciplines are also confronted with widely differing situations with regard to industrial property rights. The German and European patent law demands *technicity* as a requirement for granting a patent, which means that the invention must be based on technical considerations in principle.

Even if the term *technicity* is subject to broad interpretation in patent law today, it almost completely excludes the scientific findings of the humanities, social and cultural studies. However, the possibility of patenting in particular leads to the situation that many institutions of engineering and natural sciences create the organisational preconditions to identify patent-worthy innovations, such as in the form of a patent representative, and—given a promising marketability—also apply for a patent. Many institutes and universities also maintain a close working relationship with patent marketing agencies, often even with financial participation by the universities.

Given this background information, we can assume that potential innovation in patent-relevant institutions of engineering and natural sciences are also recognised beyond the research findings, externalised and evaluated with regard to their patent viability. This should result in a much lower number of start-ups based on tacit knowledge in these academic disciplines compared to the humanities, social and cultural studies.

The likelihood that spin-offs emerge on the basis of tacit knowledge is dependent on the academic discipline of the parent institute.

H 2.a The likelihood of start-ups based on codified knowledge is positively related in engineering and natural sciences.

H 2.b The likelihood of start-ups based on codified knowledge is related inversely in the humanities, cultural studies and social sciences.

3.3 Tacit knowledge and the type of start-up company

Furthermore, we expect that technological innovations have easier overall access to the codified realm of knowledge on the basis of the described correlations in the last section. Consequently, we presume that codified start-up knowledge is predominant in technology-oriented spin-offs while tacit start-up knowledge is dominant in knowledge-based service companies.

The type of start-up company is dependent upon the type of knowledge used.

H 3 There is a higher probability that codified knowledge start-ups create technology-oriented spin-offs than tacit knowledge start-ups.

4 Research design and sampling

4.1 Design of the field research

A questionnaire-based survey was selected as the study design. Spin-offs from German universities were surveyed within the scope of this study. These spin-offs were mostly selected on the basis of Internet research conducted in the fall of 2009. University websites and websites of the university's own or related start-up consultancies, incubators and start-up centres were evaluated for this purpose. This data was supplemented by evaluating reports and publications by the universities regarding start-up activities. This is how it was possible to identify 621 spin-offs from German universities. These companies were sent a one-page questionnaire in November 2009, which was simultaneously made available on the Internet. A personalised reminder was sent via email after 1 week. A total of 148 responses were received, which corresponds to a response rate of 23.8 %. The sample was optimised by removing four companies because they stated that the knowledge acquired at the university had no significance for their start-up project. Since no transfer process took place in this case, these companies are excluded from the group of spin-offs.

4.2 Sample characteristics

The surveyed spin-offs were founded between 1973 and 2009. The majority of companies (77 %) were founded in the decade between 1998 and 2009; 22 % of the sampled companies fall in the time period between 1999 and 1988. Only one company, which was founded in 1973, falls within the time period before 1988. All companies indicated that they had between 0 and 15 employees at the time of the foundation. The largest spin-off company now has 135 employees (Table 1).

The companies were asked whether they consider themselves a *knowledge-based service company* or a *technology-oriented company*. 43 % (n = 55) of the companies view themselves as a *knowledge-based service company* and 57 % (n = 72) of the surveyed companies consider themselves a *technology-oriented company*. These figures do not include the 11 companies (8 %) that did not consider themselves as belonging to either category or did not provide any information in the survey regarding the type of the company. The structure of spin-off companies determined in the survey is also supported by other empirical studies. Spielkamp et al. (2004) concluded that spin-offs do not deviate from the general industry pattern of knowledge-intensive economic sectors. 55 % of companies in this industry are technology-oriented (45 % technology-oriented services, plus 10 % high-tech industry) while 45 % are categorised as knowledge-intensive services.

The companies were also asked about the institution from which they spun out. The predominating share was spin-offs from universities (59 % from universities and 24 % from technical universities) and a smaller portion of 13 % from universities of applied sciences (Table 2).

4.3 Operationalising the terms of codified/tacit knowledge

Differentiating the surveyed spin-offs according to the type of start-up knowledge was the central objective of the study's survey questions. The surveyed spin-offs were assigned to one of the two following categories:

> Tacit start-up knowledge: The spin-off was based on knowledge that was only present at the university in a tacit form.

Tables 1 Descriptive statistics

	N	Minimum	Maximum	Mode	Mean	S
Number of members in start-up team	141	1	4	2	2.43	0.99
Number of employees at time of survey (11/2009)	137	0	135	2	11.40	19.32
Number of employees in start-up year	136	0	15	2	2.20	1.84
Founding year	139	1973	2009	2001		

Survey of spin-offs by German universities (2009); 621 distributed surveys; 148 responses (23.8 %)

Table 2 Descriptive statistics: parent institute of the spin-offs (N = 143)

University	Technical university	University of applied sciences	Non-university research institutes
84	34	19	6
58.7 %	23.8 %	13.3 %	4.2 %

Codified start-up knowledge: The start-up was based on knowledge that was recorded at the university in an explicit or codified form.

This classification is based on nine indicators, which have been derived from the described theoretical model of knowledge with the differentiation of tacit and codified knowledge. The applied indicators describe the characteristics of the two realms of knowledge within the context of universities and research institutes. Three indicators describe the characteristics of tacit knowledge; six indicators describe the characteristics of codified knowledge. The indicators were sampled by nine closed questions with the available answers of "Applies" and "Does not apply" (Table 3).

The selected survey design requires the respondent to make a "subjective" evaluation, which could be viewed as a methodical weakness of our study. However, this subjectivity lies in the nature of tacit knowledge that is not documented and therefore tied exclusively to persons. Empirical studies on tacit knowledge only allow for objective and indirect measurement by measuring factors such as the frequency and duration of face-to-face interactions or the spatial proximity between certain protagonists (e.g. Agrawal 2001; Audretsch and Stephan 1996), or simply a direct measurement, which is then inevitably subjective. Indirect methods generally just allow the observation and identification of possible communication channels through which tacit knowledge could be transported. We decided on a direct measurement in our study because we wanted to get close to the knowledge itself, which represents the core element of our study. This necessarily also requires approaching an individual's personal, subjective area (Ambrosini and Bowman 2001). We were aware of the inherent challenge that is necessarily associated with recording tacit knowledge in a direct survey and therefore selected multiple indicators for both realms of knowledge that were derived from the theoretical model of knowledge shown above.

The evaluation of tacit start-up knowledge was only performed for unambiguous findings in order to account for the fact that literature does no yet agree on a final clear definition of the tacit knowledge phenomenon. A spin-off was only assigned to the category of *tacit start-up knowledge* if *all* six indicators of codified knowledge were negated by

Table 3 Indicators of codified and tacit knowledge within the context of spin-offs from universities

Which of the following statements applies to the type of knowledge that was the basis for the start-up?	Indicator	Definition of the variables
It was described completely in publications	Codified knowledge	Applies = 1
It was the basis of a university patent	Codified knowledge	Does not apply = 0
It was fully documented and described in detail within the university	Codified knowledge	
The stages of creation and development were documented	Codified knowledge	
The areas of application were documented (manuals, work procedures, etc.)	Codified knowledge	
The handling of problems was described	Codified knowledge	
It was not documented or only documented incompletely	Tacit knowledge	
It was personal practical knowledge, which was only known to me and/or a few other persons (e.g. members of a work group)	Tacit knowledge	
It was a non-documented experience	Tacit knowledge	

Table 4 Academic discipline of founders/type of start-up company

	Tacit start-up knowledge (%)	Codified start-up knowledge (%)	Fisher's exact test*
Language and cultural studies	8 (57)	6 (43)	1.000
Law and economic sciences	12 (55)	10 (45)	1.000
Natural sciences	15 (48)	16 (52)	0.424
Health sciences	1 (20)	4 (80)	0.175
Engineering sciences	36 (46)	40 (54)	0.066
Agriculture and forestry sciences	2 (50)	2 (50)	1.0
Humanities, social and cultural studies	6 (67)	3 (33)	0.513

Multiple answers were possible

* Fisher‘s Excat Test-significance (2-tailed)

the answer "Does not apply". Spin-offs with positive indicators for both tacit and codified knowledge were assigned to the category of *codified start-up knowledge*.

4.4 Control Variables

The founders' academic degree/area of study was queried with an open question in order to assign the two differentiated types of start-up knowledge to individual academic disciplines. Multiple answers were expressly allowed for this question. The founders were assigned to seven categories on the basis of their responses. Interdisciplinary start-ups with multiple responses were assigned to multiple categories. The start-up was only assigned once to each category in case of multiple responses for academic degrees assigned to the same category. Assignment of the study area was performed according to the classification of the German Federal Employment Agency (Bundesagentur für Arbeit), which has already proved useful in other empirical studies (Josten et al. 2008) (Table 4).

Starting with the theoretical model of knowledge, we infer that access to an organisation's tacit realm of knowledge mostly occurs on the level of individual work groups. Furthermore, we also assume that a group has broader access to the realm of tacit knowledge than an individual. We therefore asked companies whether they were founded by an individual or by a team: 113 (80 %) of the surveyed companies were founded by teams and 28 (20 %) were individual start-ups.

In addition, the correlation between the type of start-up knowledge and the type of company was surveyed. The spin-offs' classification was queried with a closed question by selecting one out of three possible answers. The available responses allowed a classification according to knowledge-based service, technology-oriented company or other.

5 Results

5.1 Factor analysis

Exploratory factor analysis was performed for the indicators of knowledge relevant to start-ups (Table 5). The analysed data could be reduced to two factors whereby all items for codified start-up knowledge were described by one factor and all items for tacit knowledge by the other factor. Internal consistency reliability was analysed using

Table 5 Results of factor analysis with a rotated component matrix

Which of the following statements apply with regard to the type of knowledge that was the basis of the start-up?	Factor 1 Codified knowledge start-up	Factor 2 Tacit knowledge start-up
It was described completely in publications	**0.639**	−0.283
It was the basis of a university patent	**0.397**	−0.377
It was fully documented and described in detail within the university	**0.619**	−0.479
The stages of creation and development were documented	**0.629**	−0.377
The areas of application were documented (manuals, work procedures, etc.)	**0.684**	0.078
The handling of problems was described	**0.636**	0.154
It was not documented or only documented incompletely	−0.357	**0.563**
It was personal practical knowledge, which was only known to me and/or a few other persons (e.g. members of a work group)	0.299	**0.740**
It was a non-documented experience	−0.098	**0.755**

Measure of sampling adequacy according to Kaiser–Meyer–Olkin = 0.74

Extraction method: Principal Component Analysis

Rotation method: Varimax with Kaiser Normalisation

The cumulative proportion of variance explained by the two factors is 50.0 %

Loadings with an absolute value of 0.4 were considered significant

Kuder-Richardson-Formula (KR-20) factor 1 = 0.722, factor 2 = 0.518

Kuder-Richardson (KR-20). The codified factor resulted in a KR-20 of 0.72 and the tacit factor in a KR-20 of 0.58. A KR-20 greater than 0.5 is generally considered sufficient for exploratory examinations, which places the reliability of the generated tacit factor into the lower acceptable range. However, it should be noted that tacit knowledge is difficult to capture empirically due to its nature. Consequently, the results of the reliability test are considered adequate.

The factor-loading pattern paints a clear dichotomous picture. As a result, Hypothesis 1 can be accepted. Spin-offs can be separated into the groups of *codified knowledge-based start-ups* and *tacit knowledge-based start-ups,* depending on the start-up knowledge that was used. The group of spin-offs with tacit start-up knowledge includes 79 companies (55 %) of the sample; the group of spin-offs with codified start-up knowledge includes 65 companies (45 %) (Table 6).

Table 6 Frequency of codified and tacit knowledge start-ups

	N	Codified (%)	Tacit (%)
All companies	144	65 (45)	79 (55)
Including			
Technology-oriented companies	72	36 (50)	36 (50)
Service companies	55	22 (40)	33 (60)
Humanities, social and cultural studies*	19	6 (32)	13 (68)
Engineering and natural sciences*	87	45 (52)	42 (48)

* Companies that were founded by interdisciplinary teams and can be categorised in both the humanities and engineering were excluded

5.2 Regression Analysis

We approached the tacit realm of knowledge itself in the next step of the analysis. With the help of a logistic regression (Model 1), we tested the set of Hypothesis 2. We investigated the question as to whether there is a correlation between the dichotomous dependent variable of codified versus tacit start-up knowledge and specific academic disciplines. The academic disciplines of engineering and natural sciences were combined for this analysis because we assumed there is a strong correlation in both disciplines between research findings and exploitation relevance, and patenting is generally possible in both disciplines. The second group includes the humanities, social and cultural studies. The pure research findings are often not relevant for exploitation on their own and patenting of scientific research results is generally not possible. (The group of health care, agriculture and forestry sciences could not be assigned unambiguously to the two above-mentioned groups.) In order to avoid distortions, the analysis excluded interdisciplinary start-ups, i.e. companies that were established by founding members from both technological disciplines and non-technological disciplines.

Team creation was integrated into the model as a control variable. We must assume that a joint start-up by multiple employees has broader access to the parent institute's tacit realm of knowledge as a team in comparison to an individual founder.

The regression model provides an unexpected result (Table 7). On a significance level of 0.05, we cannot observe any correlation between the parent institute's academic discipline and the creation of codified or tacit knowledge start-ups. As a result, Hypotheses 2a and 2b cannot be confirmed. However, there is a tendency for the codified realm of knowledge of start-ups to be used to a higher degree ($p = 0.060$) in engineering and natural sciences. The start-ups from different academic disciplines apparently use both realms of knowledge equally. The expected higher exploitation relevance of research findings in engineering and natural sciences evidently does not result in an increasing use of knowledge from the codified realm of knowledge by start-ups.

When looking at it from a process perspective, we could view both realms of knowledge as an input variable and the start-up companies that were created as the output. We evaluated the question as to what degree the input (codified vs. tacit knowledge) influences the output, i.e. the type of spin-off company created, in the following analysis step. In order to evaluate Hypothesis 3, we also constructed a logistic regression model (Model 2). The company type of technology-oriented versus service company was defined as the dependent-dichotomous variable. The type of start-up knowledge (codified/tacit) was introduced into the model as the independent variable and the academic discipline was included as the control variable (Table 8).

Table 7 Logistic regression Model 1

Dependent variable = tacit versus codified, N = 137				
Predictor	B	Wald	p	e^{β}
Engineering and natural sciences	0.831	3.536	0.060	2.296
Humanities, social and cultural studies	0.035	0.003	0.956	1.036
Team creation	0.450	1.008	0.316	1.568

Overall model evaluation: −2Log-Likelihood = 182,162, Cox and Snell $R^2 = 0.044$, Nagelerk $R^2 = 0.058$

Table 8 Logistic regression Model 2

Dependent variable knowledge-based service versus technology-oriented company, N = 123				
Predictor	B	Wald	p	e^{β}
Codified versus tacit	−0.010	0.001	0.981	0.990
Engineering and natural sciences	0.867	3.440	0.064	2.379
Humanities, social and cultural studies	−21.204	0.000	0.998	0.000

Overall model evaluation: −2Log-Likelihood = 134,489, Cox and Snell $R^2 = 0.239$, Nagelerk $R^2 = 0.321$

It was quite surprising that we could not observe any correlation between the type of knowledge relevant to start-ups and the type of the established spin-off company (knowledge-based or technology-oriented company). The use of codified knowledge or tacit knowledge has no significant influence on the type of the start-up company ($p = 0.981$). There is a tendency towards start-ups from the disciplines of engineering and natural sciences more frequently leading to technology-oriented companies ($p = 0.064$). However, this correlation is not significant on a significance level of 0.05. Or in other words: On the basis of tacit knowledge, there is an equal probability that start-ups will emerge as either technology-oriented or knowledge-based service companies.

5.3 Significance of tacit knowledge-based start-ups

In addition to the type of the start-up company, we obviously need to ask the question about the existence of additional characteristics in which the two forms of start-up could differ from each other. We put an emphasis on the input variable in our study, which means the start-up knowledge. Consequently, our research design is only suitable to a very limited degree for making additional qualitative statements about tacit start-up companies. Due to the high quantitative proportion of tacit start-up companies in start-up activities, the question arises as the significance of these companies. Even if our study only allows for very limited statements on this issue, there are still some recognisable initial indications. There is no doubt that evaluating the significance of tacit knowledge-based start-ups from universities and research institutes is a complex issue, which can only be examined by means of a strong focus within the scope of the study. We selected the number of jobs created at spin-off companies as the indicator of significance in our first approach. This key indicator is also used in relation to economic policy for the evaluation of knowledge transfers.

The average number of jobs created at time of formation and at time of survey was calculated for both groups of codified and tacit knowledge start-ups. This was then subjected to a statistical testing of equivalence. However, it became apparent that the resulting data was unsuitable for equivalence testing. The overall sample size was too small and the mean variances differed too much (cf. Wellek 2010).

As an alternative, a test was used to determine whether a significant difference existed between the number of jobs created by tacit and codified knowledge start-ups. A t-test process for means was performed to that end. In an initial step, the appropriateness of the selected process of mean comparison was tested and confirmed the normal distribution of the variables by a Kolmogorov–Smirnov test for normality. The sample of tacit knowledge start-ups have an average of 11.1 employees (n = 74) while codified knowledge start-ups have an average 11.8 employees (n = 63). The p-value of 0.818 does not indicate any significant difference of average means. The result provides a indication that the

Table 9 Comparison of means for employees in tacit and codified knowledge start-ups (two-sample *t* test with equal variance)

	Time of formation	Time of survey
Employees: mean (SD)	Tacit knowledge-based (n = 73): 2.1 (1.5)	Tacit knowledge-based (n = 74): 11.1 (15.1)
Employees: mean (SD)	Codified knowledge-based (n = 63): 2.3 (2.2)	Codified knowledge-based (n = 63): 11.8 (23.5)
Levene's tests for equality of variances	F = 1.158, $p = 0.284$	F = 0.616, $p = 0.434$
t Test	t = 0.648, $p = 0.518$	t = 0.230, $p = 0.818$

employment effect of tacit and codified knowledge start-ups is similar and the two groups do not differ significantly with regard to the number of jobs created. The evaluation of employment at the time of formation shows a similar picture (Table 9).

Our findings are supported by other studies. The previously cited empirical study by Spielkamp et al. (2004) shows a similar picture: An average of 34,000 full-time jobs were created per year in the second half of the 1990s by 6,800 spin-off start-ups in Germany; of these, 12,500 full-time jobs were at 2,600 transfer spin-offs and 21,000 full-time jobs at 4,200 competence spin-offs. The average number of jobs created is therefore comparable with regard to the direct exploitation of research findings (transfer spin-offs: 4.8 jobs/year) and spin-offs beyond research findings (competence spin-offs: 5.0 jobs/year) (Spielkamp et al. 2004).

Due to this background, we assume that there is also no significant difference with regard to jobs created by tacit and codified knowledge start-ups. Nevertheless, these questions would have to be clarified in a more extensive study, which should have the goal of also researching and describing tacit start-up companies on a qualitative basis.

5.4 Evaluation summary of the research findings

The results of the statistical hypothesis test are summarised in Table 10. As expected, tacit knowledge-based start-ups predominate the start-up activity at universities. However, these results surprisingly indicate that the scientific discipline of the parent institute has significantly less impact on the type of start-up knowledge used than expected. Tacit knowledge-based start-ups constitute an important pillar of start-up activity in all academic disciplines.

In addition to quantitative findings, the research results also allow initial qualitative assessments of tacit knowledge-based start-ups. Tacit knowledge-based start-ups lead to technology-oriented companies, as well as to knowledge-based service companies. The research findings also indicate that tacit knowledge-based start-ups create the same number of jobs as spin-offs from universities that develop directly from research findings.

6 Discussions

Within the scope of our study, we investigated from which realm of knowledge university spin-offs draw their knowledge as the foundation of their start-up company. The most important result was that not only documented research findings are the basis of spin-offs

Table 10 Summary of hypothesis-testing results

	Hypothesis	Accept/reject
H1	Spin-offs can be categorised in two general groups according to the knowledge they employ: One group primarily uses codified knowledge while the other group predominantly uses the tacit knowledge of the parent institute	Accept
H2a	The likelihood of start-ups based on codified knowledge is positively related in engineering and natural sciences	Reject
H2b	The likelihood of start-ups based on codified knowledge is related inversely in the humanities, cultural studies and social sciences	Reject
H3	There is a higher probability that codified knowledge start-ups create technology-oriented spin-offs than tacit knowledge start-ups	Reject

but that components of the university's tacit knowledge are also an important factor in a university's start-up activities.

6.1 Theoretical implications

Our study conforms to previous research on tacit knowledge at universities and research institutes, all of which showed that tacit knowledge plays an important role in transfer activities. Despite its great significance, the universities' tacit realm of knowledge has received relatively little attention from researchers to date. The lack of attention paid to tacit start-up knowledge is reflected in the general and false perception of start-up potential. Perception that is solely limited to the codified realm of knowledge offers very little or no indication for a knowledge transfer or a spin-off in a historical, philosophical or even political consulting institute. Additionally extending perception to the tacit realm of knowledge also makes transfer-relevant knowledge visible in areas where it has not been previously expected. An approach solely oriented towards the marketing of research findings and codified knowledge results in these institutions being completely disregarded by transfer offices and university start-up consultants during the process of identifying start-up and innovation potential.

The observed importance of tacit knowledge in the start-up process suggests that not only start-up potentials but also innovation potentials in general are hidden within the realm of tacit knowledge. The question about economically exploitable tacit knowledge is therefore not limited to the spin-off process; instead, it relates in general to the topic of knowledge transfer from universities and research institutes.

6.2 Practical implications

An important finding of our study is that the insight that the tacit realm of knowledge should be included in all considerations related to knowledge management at universities. If some components of knowledge are not externalised at universities, this does not mean that they have no economic value. In contrast to these assertions, the practice of Technology Transfer Offices (TTO) is often solely limited to the research findings. Our study shows that a large part of the university's exploitation-relevant knowledge is not published and therefore remains unnoticed by the TTOs.

Yet, the instruments employed by the management of institutes and the TTOs for the systematic identification of exploitation potentials are often inadequate due to this background. For example, an entire series of research institutes in Germany has started having all publications vetted by a patent attorney or an exploitation specialist for potentially exploitation-relevant knowledge. This process is intended to capture all exploitation-relevant knowledge. This is an erroneous belief because this approach remains incomplete if exploitation-relevant knowledge does not appear in the publications. Capturing the tacit realm of knowledge poses a fundamental, new challenge for knowledge management at universities. This is actually about identifying exploiting relevant components of knowledge that were previously not documented and sometimes known only to individual work groups. The challenge to systematically identify tacit and simultaneously exploitation-relevant knowledge beyond research results leads to the future role of research.

6.3 Limitation and future research

There is apparently a lack of models, methods and processes for a systematic identification of tacit spin-off and the potential of innovations. The *screening methods* applied by start-up consulting firms and transfer offices today—namely, measures and processes for the systematic detection of start-up and/or transfer potentials—are then actually unsuitable for identifying the potential of tacit knowledge-based start-ups. *Technology scouting*, also called *technology audits*, is the most frequently used approach; this is mostly performed in the form of visits to institutes by qualified industry experts. Both methods target main research areas and research findings and cannot access the tacit realm of knowledge.

Appropriate methods and processes must be developed for externalising the related exploitation and start-up potential in the form of a scientific institution's tacit knowledge, as well as making it accessible for the transfer process.

References

Agrawal, A. (2001). University-to-industry knowledge transfer: Literature review and unanswered questions. *International Journal of Management Reviews, 3*(4), 285–302.

Agrawal, A. (2006). Engaging the inventor: Exploring licensing strategies for university inventions and the role of latent knowledge. *Strategic Management Review, 27*, 63–79.

Ambrosini, V., & Bowman, C. (2001). Tacit knowledge: Some suggestions for operationalization. *Journal of Management Studies, 38*(6), 811–829.

Audretsch, D. B., & Stephan, P. E. (1996). The case of biotechnology. *The American Economic Review, 86*(3), 641–652.

Barley, S. R., & Bechky, B. A. (1994). In the backrooms of science: The work of technicians in science labs. *Work and Occupations, 21*(1), 85–126.

Djokovic, D., & Souitaris, V. (2008). Spinouts from academic institutions: A literature review with suggestions for further research. *The Journal of Technology Transfer, 33*, 225–247.

Druilhe, C. L., & Garnsey, E. (2004). Do academic spin-outs differ and does it matter? *Journal of Technology Transfer, 29*, 269–285.

Gorman, M. E. (2002). Types of Knowledge and Their Roles in Technology Transfer. *Journal of Technology Transfer, 27*, 219–231.

Güldenberg, S., & Helting, H. (2004). Wissensmanagement falsch verstanden? Eine Fortsetzung des Dialoges zur Neuorientierung des Wissensmanagement. *Die Betriebswirtschaft, DBW, 64*(5), 523–537.

Howells, J. (1996). Tacit knowledge, innovation and technology transfer. *Technology Analysis & Strategic Management, 8*(2), 91–103.

Josten, M., van Elkan, M., Laux, J., & Thomm, M. (2008). *Gründungspotenziale bei Studierenden. Zentrale Ergebnisse der Studierendenbefragung an 37 deutschen Hochschulen*. Bonn/Berlin: Bundesministerium für Bildung und Forschung (Hrsg.).

Leonard, N., & Insch, G. S. (2005). Tacit knowledge in academia: A proposed model and measurement scale. *The Journal of Psychology: Interdisciplinary and Applied, 136*(6), 465–512.

Lowe, R. A. (2006). Who develops a university invention? The impact of tacit knowledge and licensing policies. *Journal of Technology Transfer, 31*, 415–429.

Nelson, R., & Winter, S. (1982). *An evolutionary theory of economic change*. Cambridge, MA: Harvard University Press.

Nonaka, I., & Takeuchi, H. (1997). *Die Organisation des Wissens: Wie japanische Unternehmen eine brachliegende Ressource nutzbar machen*. Frankfurt am Main: Campus.

Pearson, A., Brockhoff, K., & von Boehmer, A. (1993). Decision parameters in global R&D management. *R&D Management, 23*(3), 249–263.

Pisano, G. P., Shan, W., & Teece, D. J. (1988). Joint ventures and collaboration in the biotechnology industry. In D. C. Mowery (Ed.), *International collaborative ventures in U.S. manufacturing* (pp. 183–222). Cambridge, MA: Ballinger Publishers.

Polanyi, M. (1966). *The tacit dimension*. Garden City, NY: Doubleday & Company, Inc.

Polanyi, M. (1985). *Implizites Wissen (orig.: The Tacit Dimension, Garden City/N.Y. 1966)*. Frankfurt am Main: Suhrkamp.

Rothaermel, F. T., Agung, S. D., & Jiang, L. (2007). University entrepreneurship: A taxonomy of the literature. *Industrial and Corporate Change, 16*(4), 691–791.

Spielkamp, A., Egeln, J., Gottschalk, S., & Rammer, C. (2004). Spin-offs in Germany: Conceptual considerations and empirical evidence. In M. Dowling, J. Scmude, & D. Knyphausen-Aufsess (Eds.), *Advances iin Interdisziplinary European Entrepreneurship Research (vol. 3)* (pp. 153–181). Germany: LIT Verlag Münster.

Sternberg, R. J. (1994). Tacit knowledge and job success. In N. Anderson & P. Herriot (Eds.), *Assessment and selection in organisation: Methods and practice for recruitment and appraisal* (pp. 27–39). London: JohnWiley.

Sternberg, R. J., Forsythe, G. B., Hedlund, J., Horvath, J. A., Wagner, R. K., Williams, W. M., et al. (2000). *Practical intelligence in everyday life*. New York: Cambridge University Press.

Sternberg, R. J., Wagner, R. K., Williams, W. M., & Horvath, J. A. (1995). Testing common sense. *American Psychologist, 50*, 912–927.

Wagner, R. K. (1987). Tacit knowledge in everyday intelligence behavior. *Journal of Personality and Social Psychology, 52*, 1236–1247.

Wellek, S. (2010). *Testing statistical hypotheses of equivalence and noninferiority*. London: Chapman & Hall.

Zucker, L. G., & Darby, M. R. (2001). Capturing technological opportunity via Japan's star scientists: Evidence from Japanese firms' biotech patents and products. *Journal of Technology Transfer, 26*, 37–58.

Zucker, L. G., Darby, M. R., Armstrong, J. (1994). *Intellectual capital and the firm: The technology of geographically localized knowledge spillovers*. National Bureau of Economic Research Working Paper No. 4946.

Zucker, L. G., Darby, M. R., & Armstrong, J. (1998a). Geographically localized knowledge: Spillovers or markets? *Economic Inquiry, 36*(1), 65–86.

Zucker, L. G., Darby, M. R., & Armstrong, J. (2002). Commercializing knowledge: University science, knowledge capture, and firm performance in biotechnology. *Management Science, 48*(1), 138–153.

Zucker, L. G., Darby, M. R., & Brewer, M. B. (1998b). Intellectual human capital and the birth of U.S. biotechnology enterprises. *American Economic Review, 88*(1), 290–306.