J Technol Transf (2016) 41:1077–1112
DOI 10.1007/s10961-016-9486-3

Technology commercialization: a literature review of success factors and antecedents across different contexts

Markus A. Kirchberger[1] · **Larissa Pohl**[1]

Published online: 24 June 2016

Abstract This paper provides a systematic review of the current literature on technology commercialization. It serves to establish a foundation for the following empirical and theoretical contributions. Technological inventions are fundamental for a country's economic growth. However, in order to actually generate value for society and profits for the involved companies, these inventions need to be successfully transferred to the market. Therefore, newly developed technologies need to be integrated into products which sell. In particular, our study focuses on the different interaction channels through which technology commercialization occurs. We analyze main groups of institutions, which can either act as developers of technologies and/or organizations bringing these technologies to the market: Universities and research institutes, technology startups, and established companies. We propose a theoretical framework of possible interactions between these organizations and analyze the success factors within the respective channels. Based on the systematic review of 140 articles, key characteristics of the technology development organizations are analyzed with regard to the different possible channels available to commercialize their technology.

Keywords Technology commercialization · Transfer channels · Success factors · Technology innovation

✉ Markus A. Kirchberger
markus.kirchberger@kit.edu

[1] Chair for Management Accounting, Karlsruhe Institute of Technology, Kaiserstraße 89, 76131 Karlsruhe, Germany

1 Introduction

In this literature review we present antecedents and success factors of technology commercialization in different settings. We want to motivate this article with the following example: In 1894 the physicist Alfred M. Mayer discovered that one tone could make another one inaudible. This led to the discovery of auditory masking and much later to the invention of the mp3 music compression standard. However, the first mp3 players were sold only around 100 years later in the 1990s.[1] Technological progress through research is a key factor in economic growth, but in order to actually create value, inventions need to be successfully transferred to the market (Adams 1990; Eurostat 2008; Spann et al. 1995).

The mp3 example stated above is probably what many people picture when they think about innovation and technology commercialization. Obviously not all inventions originate from basic university research. There are other sources of technologies too, such as established companies or startups. In this review we refer to the source of a technology, such as a university, technology institute, specialized startup, or research department in an established firm as "technology party".

The value is created primarily when the products that embody the new technology outperform established products or when the technology enables the development of completely new products which meet the consumers' requirements (Maine and Garnsey 2006). This means, whether the commercialization is a success or not, is mainly dependent on how the consumers or business customers value the technology (Lo et al. 2012). On the market side there are also different options of how technology may be commercialized. An established firm may use a new technology in its product portfolio or a startup may be founded around the new technology. In this review we refer to the commercializing entity as "market party". With commercialization channel we refer to what type of parties work together to bring the technology to the market (see Table 2).

Not all technologies actually achieve market success and generate profits (George et al. 2002; Markham and Lee 2013). In a lot of cases the problematic part is not so much the invention itself, but the market commercialization of the newly developed technology (Gans and Stern 2003). The commercialization of technologies is a difficult process which includes the identification and evaluation of the technology's market potential, as one of the key elements (Dorf and Worthington 1987). With "antecedents and success factors" we refer to causes which either make the commercialization possible or improve its commercial outcome. Understanding these factors helps to bring more research results to a practical use. In this review we give an overview about the research on these factors and in what context they have been researched already. This may help fellow researchers to find gaps in the literature and inspire practitioners to look at factors which may aid them in technology commercialization.

Source and destination of a technology can be in the same organization; however, the increasing complexity of products and processes, combined with the rapid pace of technological change and the shorter life cycles of products, has led to a growing R&D and commercialization cooperation between organizations. This has been captured, for example, in the literature on open innovation (Chesbrough and Crowther 2006). For organizations which lack human resources or sufficient technology specific knowledge, cooperation might even be the only possibility to bring their technology to the marketplace (Markman et al. 2008). Furthermore, the commercialization path depends on the type of

[1] At http://www.iis.fraunhofer.de/en/ff/amm/mp3history.html, website is in German, accessed on 19 April 2015.

innovation and the risk that is run with the commercialization of the technology (Walsh 2012). Thus, besides the possibility of entering the market on their own, technology developers need to explore further options to commercialize their inventions by interacting with other organizations (Maine and Garnsey 2006).

Researchers like Clarysse et al. (2011) and Mustar et al. (2006) emphasize how commercialization channels may be different. In this literature review we try to identify common factors of success across commercialization channels. The primary objective of this review is to enhance the understanding of the possible commercialization channels between technology developers (such as universities and specialized startups) and organizations that try to commercialize the newly developed technologies. Furthermore, our aim is to identify factors that influence technology commercialization success. We categorize these factors and reveal commonalities and differences between the channels. Additionally, we show the comprehensiveness of technology commercialization research and the types of research employed.

These objectives will be achieved through a systematic literature review of mostly empirical research papers on organizations that commercialize technologies. The research related to the transfer and commercialization of new technologies has been conducted by different disciplines (e.g., economics, management, marketing, and engineering) and from various theoretical perspectives (e.g., organization theory, resource-based view, institutional theory, and agency theory) (c.f., Balachandra and Friar 1997; Djokovic and Souitaris 2008; Garcia and Calantone 2002; Perkmann et al. 2013). Some specialized journals focus almost exclusively on this research area (e.g., *Journal of Technology Transfer (this journal)*, and *International Journal of Technology Transfer and Commercialization*). Within this field we found three major themes: Studies on technology commercialization including universities or other public research institutes, technology commercialization through startups, and technology commercialization through established companies. What we did not include in our review are articles that discuss macroeconomic impacts of technology transfer, the role of governments (e.g., regarding regional development), or those studies that concentrate mainly on financial and legal aspects of technology commercialization, as they are not relevant to our research objectives. We excluded these types of studies because we want to focus on the interaction between parties and the outcome of technology commercialization.

Research on technology commercialization is increasingly popular (see Fig. 1). The figure shown is the result of a quick search for the term "technology commercialization" in the SCOPUS literature database. Yet, to the best of our knowledge, there is no literature review on the different channels in combination with success factors of technology commercialization.

However, there are a number of comparable literature reviews (see Table 1). There is a large volume of current literature describing in detail specific aspects of technology commercialization (e.g., role of Technology Commercialization Offices in Siegel et al. (2007), university entrepreneurship in Markman et al. (2008) and Rothaermel et al. (2007), corporate venturing in Narayanan et al. (2009)), but with little emphasis on the overall picture of technology commercialization channels. Thus, this paper contributes to the existing literature by providing a comprehensive and systematic overview of the current literature on technology commercialization channels in order to provide a better understanding of the factors that have already been researched in this field.

The remainder of this paper is organized as follows: In the first section, we will give some more details on the topic and present the theoretical framework on which our analysis is based. This framework describes different channels between technology developers and

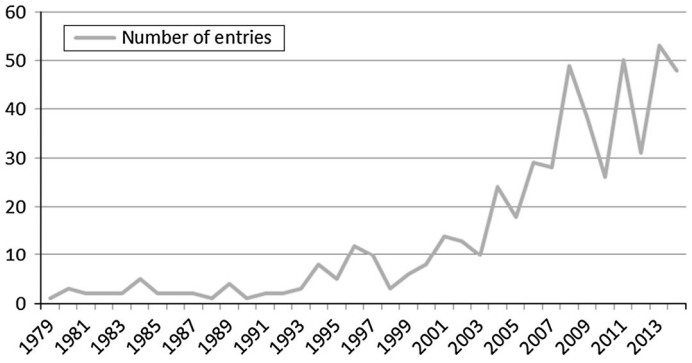

Fig. 1 Technology commercialization term frequency in Scopus

Table 1 Literature reviews about technology commercialization

Author	Journal	Focus	Literature base
Dahlander and Gann (2010)	Research Policy	Open innovation	102 Articles
Djokovic and Souitaris (2008)	The Journal of Technology Transfer	Research spin-outs	103 Articles
Markman et al. (2008)	Journal of Management Studies	Commercialization modes of universities	Unclear
Narayanan et al. (2009)	Research Policy	Key findings in corporate venturing research	83 Articles
Rothaermel et al. (2007)	Industrial and Corporate Change	University entrepreneurship	173 Articles
Siegel et al. (2007)	Oxford Review of Economic Policy	University policies and antecedents of commercialization	Unclear
Song and Di Benedetto (2008)	Journal of Product Innovation Management	Success factors of new ventures	31 Articles

organizations commercializing the technology. In the next section, we describe the method used in this review and explain in detail the search procedure we applied in our systematic review. Our findings are split into two parts: The first part is on the different commercialization channels which we identified and intermediaries in technology commercialization. The second part is focused on the antecedents and success factors of technology commercialization which we identified. Finally, we draw conclusions on channels and success factors, derive theoretical and practical implications, present limitations of our study, and suggest future directions for research.

2 Conceptual background

Due to the intensive research on the topic and the cross disciplinary nature of the research area, there are many different definitions and criteria for *technology commercialization* (Zhao and Reisman 1992). The terms "technology commercialization" and "technology transfer" are often used interchangeably. As we will see below, one term may even be used to define the other and vice versa. Although technology transfer and technology commercialization originally have a slightly different meaning, in the current literature these terms are often used to describe the same process. This is why, in this review, we also use the terms interchangeably. Yet there are publications which see technology transfer and technology commercialization as distinct phases (e.g., Autio (1994)). Economists were the first to use the term "technology transfer" (Zhao and Reisman 1992) and the term originally referred to the development and diffusion of innovations within society, rather than commercialization in the sense of bringing technology onto the market (Galbraith et al. 2006). Papers that only focus on these economic impacts or on governmental policies related to technology commercialization are not included in our review, since they do not address our research objectives, which is concerned with understanding individual transactions. The commercialization of technologies can be viewed as transferring technology innovation into products which sell.

We found three definitions of technology transfer and commercialization which were helpful to our own conceptualization: (1) Bell (1993) defines technology transfer as a process that begins with the invention of a new technology followed by innovation, which is described as the process of commercial application and exploitation of that technology. (2) Mitchell and Singh (1996, p. 170) view commercialization as the "process of acquiring ideas, augmenting them with complementary knowledge, developing and manufacturing salable goods, and selling the goods in the market". (3) "Technology commercialization (Ambos et al. 2008) is the design, manufacturing, and marketing of products with the developed technology or the transfer of technology through licensing or other collaborative activities" (Caerteling et al. (2008, p. 143) based on Kollmer and Dowling (2004)). In the same paper, the authors also stress the collaborative effort of technology commercialization. In the context of our research, we define technology commercialization *as the process of transferring a technology-based innovation from the developer of the technology to an organization utilizing and applying the technology for marketable products*.

With regard to our review, we distinguish between three different groups of organizations that represent technology developers and commercializing organizations. These include universities and other research institutes, (technology) startups that are founded for the sole purpose of developing (and in some cases also commercializing) technologies, and established companies. The first major research field is how universities as an important developer of technologies can commercialize their inventions, either through licensing and patenting (e.g., Colyvas et al. 2002; Markman et al. 2005; Siegel and Phan 2004) or through the creation of spin-offs (e.g., Carayannis et al. 1998; Kroll and Liefner 2008; Stevens and Burley 2003). In this context, other federally-funded research institutes, such as national laboratories, are also studied (e.g., Kassicieh et al. 2002). Another important research area concerns technology startups (e.g., Gans and Stern 2003; Roure and Keeley 1990; Song and Di Benedetto 2008). They have—similar to universities—the possibility to sell or license their technologies to established companies. Another option they might consider is entering the market on their own. In this case, they develop not only the technology, but also the corresponding products, which embody the new technology.

Additionally, there is a less frequent—if not even "exotic"—form of technology commercialization channel, which is selling of the technology (or even the whole startup) to the public sector. An example of this channel form is when startups which develop defense technologies are spun-in into military defense agencies (Galbraith et al. 2004).

Larger and more established companies involved in technology development are also addressed by a substantial part of the literature on technology commercialization (e.g., Zahra and Nielsen 2002). They can, in the same way as the previously mentioned organizations, sell or license their technology to other established firms, enter the market on their own or—similar to universities—spin out new ventures. Either way, for established companies highly involved in new technology development, the successful commercialization of inventions is crucial to their profitability (Caerteling et al. 2008).

When looking at these organizations as the developers of the technology, i.e., the original organizational source of the technology, we also refer to them as the *technology party*. Each of these three types of organizations can also act as a *market party*, i.e., the organization which usually further develops the technology and then integrates it into products that can be sold in the marketplace. These channels were derived from reviewing the literature and are displayed in Table 2.

By systematically analyzing the current literature, we will describe key characteristics and success factors of these different types of cooperation. Hence, the main focus of this review lies on the different links between the technology party and the market party and the ways they work jointly in order to commercialize newly developed technologies.

3 Research design of the literature review

3.1 Article search and classification

We conducted a systematic literature review following the recommendations of White and Schmidt (2005) and Tranfield et al. (2003). The purpose of the method is to reduce the researchers' bias towards favorable studies and to make the steps undertaken for gathering the literature sources transparent (White and Schmidt 2005). We performed a three-stage search procedure with the following steps: (1) Identification of relevant journals, (2)

Table 2 Channels between technology developers and organizations commercializing technology

		Market party		
		Established companies	Technology startups	Universities and research institutes
Technology party	Universities and research institutes	(A) Joint research, selling, or licensing	(B) Spin-offs from academia	(C) Governmental institutions developing
	Technology startups	(D) Selling or licensing	(E) Market entry with own technology	(F) Spin-ins to governmental agencies
	Established companies	(G) Market entry with own technology; Selling or licensing	(H) Spin-outs from established companies	(I) Research requests by governmental institutions

identification of relevant articles within those journals, and (3) identification of relevant references cited in the articles that we selected in the second step.

(1) In the first step, we identified the most common journals in the research field. We conducted two Google Scholar searches for papers containing the exact phrases "technology commercialization" or "technology transfer". Due to its broader definition, the latter search term yielded numerous papers that were less relevant for the current review. The term technology transfer was still included because both terms are often used interchangeably. For each key term we checked the first 100 results' type of entry (e.g., articles from scientific journals, book chapters, conference papers, etc.) and selected only papers published in scientific journals. Conference papers, books and book chapters, or articles from other sources were excluded from the analysis. We looked for completed original research. Conference papers may be early stages of papers which are later published in journals; books, on the other hand, often synthesize knowledge that already published. This first search step yielded 125 relevant articles in total, published in 73 different journals. The articles that were identified in this search step are not necessarily included in our review. This step served only to identify relevant journals dealing with this research topic.

The journals in which at least three relevant articles were published were taken as a basis for the second step. Two of the journals that met this criterion were excluded. Their publication titles (*Journal of Development Economics* and *Journal of International Economics*) and journal mission statement on the website suggested that articles in these publications focus on the macro-economic perspective of technology transfer. This is also a popular research field related to technology commercialization, but not part of this paper.

Table 3 provides an overview of the seven relevant journals which served as a basis for the next step. We also report an overview on how our prediction of journal relevance played out during all search stages. In the second column we see how many relevant articles we found in the journal through Google Scholar. The third column shows how many of them we found by searching directly in the journal. The fourth column shows how many of the hits in column three matched our search criteria. The fifth column shows how many relevant papers we found in these journals through searching the papers' reference lists. Table 3 also shows that the hits in Google Scholar were a good predictor for the number of relevant papers we found in the journal.

Table 3 Overview of "hits" with search term TC in relevant journals

	Step (1)	Step (2)		Step (3)
	Google scholar	Journal	Stage 1	Stage 2
Journal				
IEEE Transactions on Engineering Management	4	40	12	1
Journal of Business Venturing	3	21	7	2
Journal of Product Innovation Management	3	42	12	1
Research Policy	10	84	11	11
Strategic Management Journal	3	19	5	0
Technovation	6	64	22	5
The Journal of Technology Transfer	10	89	13	11
Sum	39	359	82	31

To ensure relevance and high quality of the journals, we checked their rank in the VHB-Jourqual-Ranking (version 2.1), which is a ranking of business-related journals by the German Academic Association for Business Research, with journals being ranked from A+ to D1F.[2] Six of the journals were ranked as A or B journals with only one (*Technovation*) ranked as a D journal. Since this journal is very specialized, we did not exclude it despite the comparatively low ranking. Furthermore, we found seven relevant papers within this journal which indicated a high relevance. A second reason for consulting the VHB-Jourqual-Ranking, was to ensure that we did not miss any obviously fitting journal.

(2) In the second step we searched for relevant articles within each of those seven journals. As a search term we used "technology commercialization" and searched for it within the full text of the articles. Across the seven journals this yielded 359 results of which we regarded 82 as relevant (see below for more details). We only used the search term "technology commercialization" in this step because the term "technology transfer" turned out to be too broad. It gave us several thousand hits, and in the *Journal of Technology Transfer* it did not allow any meaningful selection. We assumed that through step (3) we would find papers which use "technology transfer" as a term for technology commercialization.

The relevance of a study was judged by using a list of inclusion and exclusion criteria that we defined before performing the second step of the search. These criteria are important for enabling an unbiased choice of which articles to include in the review and which not to use (e.g., Tranfield et al. (2003); White and Schmidt (2005)).

The criteria we used were as follows:

- Inclusion criteria:
  - Studies examining organizations that try to commercialize technologies (either by entering the market on their own or via channels with other organizations)
  - Studies investigating settings and factors that support a successful commercialization of technologies
- Exclusion criteria:
  - Papers that focus mainly on the macroeconomic and regional economic impacts of technology commercialization
  - Studies that focus on market imperfections and market entry timing
  - Articles that only consider financial aspects, namely, literature solely addressing venture capital
  - Papers only focusing on the development of technologies and knowledge, without any aspect of transferring or commercializing it to the marketplace
  - Papers focusing on the legal aspects of patenting and licensing

(3) In the third step the reference lists of all 84 articles identified by the second step were searched manually for references that were relevant. The initial selection was based on the title of the papers; the further selection was based on the same criteria as in the second phase. In this stage we only included papers that were published in 1980 or later. This was done solely for practical purposes regarding the availability of papers. As seen on the graphic above, an even later cut of point would not eliminate many publications. This

[2] The authors are most familiar with this rating, however, we checked it for consistency with other ratings through the Harzing overview list.

search resulted in additionally 63 papers of which 31 are published in the 7 journals identified in step (1).

3.2 Coding of information from the articles

In this section we explain how we transferred information from the papers to the database used for our analyses. We tried to be as consistent as possible but, of course, some judgment calls were necessary. To make this process as transparent as possible, we will lay down the process. After identifying the 140 articles, as mentioned above, we coded the following data from the articles:

Table 4 Number of papers per journal

Journal	Number of papers
Administrative Science Quarterly	1
American Economic Review	1
Entrepreneurship Theory and Practice	1
Harvard Business Review	2
High Technology Management Research	1
IEEE Transactions on Engineering Management	13
Industrial Management & Data Systems	1
Industry and Higher Education	1
Int. J. of Industrial Organizations	1
Int. J. of Technology Management	3
Int. J. of Technology Transfer and Commercialization	1
J. of Business Research	1
J. of Business Venturing	9
J. of Economic Behavior & Organization	1
J. of Engineering and Technology Management	2
J. of High Technology Management Research	1
J. of Management Studies	2
J. of Product Innovation Management	11
J. of Small Business Management	1
J. of Technology Transfer	23
Management Science	6
R&D Management	1
Research Policy	22
Research Technology Management	2
Strategic Management J.	5
Technological Forecasting and Social Change	1
Technovation	26
The Review of Economics and Statistics	1
Sum	140

- *Research question(s)* If the research question(s) were given we took them directly, if not, we used the intended main contribution of the article. This serves to make the focus of the papers visible.
- *Research method* The type of research used or contribution in the article, was often equivalent to the empirical method used. We differentiated between case studies, database research, expert interviews, surveys, and theory contributions. If a paper employed multiple methods we tried to select the dominant one.
- *Sample/data* We extracted the type of data the article is based on. It helps the reader to see what information the research is built on. This might be interesting in terms of regional differences or the scope of the research.
- *Key findings* To aid our coding process we made a short summary of the main contribution or insight of the articles.
- *Antecedents and success factors* Most articles contained some information about what leads to technology commercialization or what made it more successful. We took the information from the articles and categorized it into different types. To get to the final 13 factors which we report in this paper, four rounds of coding were necessary. In the first round we literally wrote down any new factors the paper reported, and this led to over 60 different factors. We found that many papers report multiple factors. In the following rounds we reduced the number of factors across the studies and also the number of factors per journal. In the second round we merged success factors with different names but the same meaning (e.g., "contact to industry partners" and "network with industry partners"). If a paper had more than five success factors, we re-examined it and retained the five factors which received the most attention in the paper. In round 3 and 4 we further reduced the number of factors by creating constructs and definitions which were comprehensive enough to united 2-3 factors.
- *Commercialization phase* We differentiated three phases of technology commercialization: (i) An early phase with a focus on initiation of commercialization, (ii) A middle phase with a focus on fostering commercialization, and (iii) A late phase with a focus on customer contact and actual sales.
- *Type of interaction* In the first round we extracted information which helped us to answer the following questions: What is the source of the technology? Through what

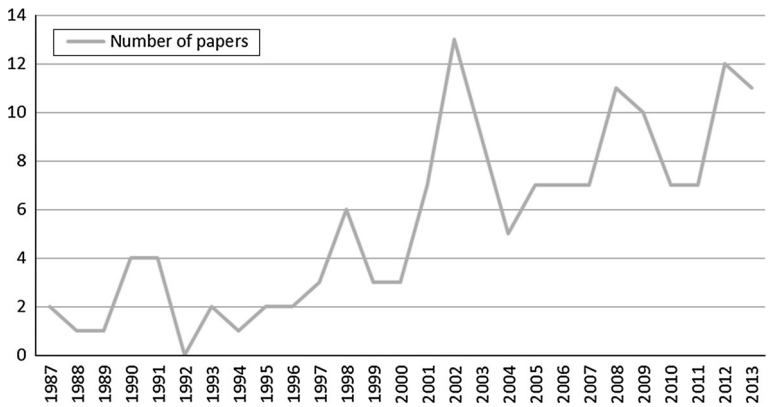

Fig. 2 Papers per year of publication

type of organization will it be brought to the market? For the second round we found it already helpful to organize the papers according to the matrix shown in Table 2.

3.3 Sample characteristics

The total of 140 papers is published across 28 different journals. Table 4 gives an overview of the distribution of the final list of articles across the different journals. The majority of papers were published in *Research Policy*, *Technovation*, *Journal of Technology Transfer*, *Journal of Product Innovation Management*, and *IEEE Transactions on Engineering Management*.

Regarding the year of publication we could find the same rise in publications over the years in our sample as in the database search displayed above (see Fig. 2). The oldest papers in our sample are from 1987, the most recent—from 2013.

In our further analysis papers could have multiple entries in the matrix with the channels (e.g., the paper reports on universities cooperating with established firms and how they spin out new ventures) and multiple success factors associated with them. To ensure that in any analysis the sum of papers is the same, we decided to count fractions of publications if a paper addressed multiple topics. That means, if a paper addressed multiple fields in the matrix or multiple success factors, a fraction equal to 1/"number of fields" or "number of success factors" was counted. An example: a paper which addressed universities commercializing by licensing to established firms and by spinning out new ventures, would contribute 0.5 to the number of studies addressing field A in our matrix and 0.5 to the number of studies addressing field B. We checked if the journals had any specific focus in terms of success factors, research method used, or commercialization channel. We did not find any specialization for success factors or for the research method used, with the exception of *IEEE Transactions on Engineering Management* which, in our sample, published predominantly survey papers. For the type of commercialization channel we found that the *Journal of Product Innovation Management* had somewhat of a focus on publications about the commercialization of technology from established companies and *Journal of Technology Transfer* had a slight focus on technology commercialization from universities.

Table 5 Matrix with commercialization channels and research methods

	Commercialization channels										
	Universities and research institutes as technology developers			Technology startups as technology developers			Established companies as technology developers			Interm.	Sum
	A	B	C	D	E	F	G	H	I		
Case study	10.50	18.00	0.50	1.00	3.00	0.00	4.50	1.50	1.00	1.00	41.00
Database research	8.00	6.25	0.00	2.50	1.25	0.00	0.25	1.25	0.50	0.00	20.00
Expert interviews	4.33	2.33	0.00	0.33	0.00	0.00	1.00	0.00	0.00	1.00	9.00
Survey	18.00	12.00	1.00	4.00	6.00	1.00	6.50	0.50	0.00	1.00	50.00
Theory	6.25	3.75	0.00	0.50	3.25	0.00	5.25	1.00	0.00	0.00	20.00
Sum	47.08	42.33	1.50	8.33	13.50	1.00	17.50	4.25	1.50	3.00	140.00

In Table 5 we report two things: (1) The number of paper per research method and (2) the number of papers per commercialization channel. We also find it interesting to report these two things in one table; because it visualizes what research methods have been used to understand which commercialization channel. As explained above, the fractions occur because if a paper reported on 2 or more channels the weight of the paper was split to the number of channels. The sum of lines and columns respectively, adds up to the 147 papers which we reviewed. In the table we see that the majority of research is on university associated technology commercialization (around 93 papers, column A and B). Slightly more papers are on universities commercializing together with established firms (column A) than on universities commercializing through spin-outs (column B). Approximately 25 papers are on established firms commercializing their technology (columns G and H) and only around 23 are on startups (column D and E). Furthermore, it is interesting to note that the majority of studies in column A are survey papers and in column B case studies. It seems the research on spin-outs relies more on qualitative studies than the research on licensing. Not surprisingly the columns C, F, and I have very few entries. Universities or similar research institutes acting as a market party are rather exotic and there are very few examples. The last column reports three studies which do not focus on any of the commercialization channels but on the role of intermediaries.

4 Commercialization channels of new technology

The first three subsections of this section are organized according to the three main types of technology development organizations (i.e., universities and research institutes, technology startups and established companies) and their possible channel modes as represented in Table 2. The success factors are discussed in the last section. The complete list of all reviewed studies is in the "Appendix". We describe our findings from the perspective of the technology developer. In the first channel we also explain the general characteristics of the technology source and take this as given in the later sections.

4.1 Universities and government-funded research institutes as technology developers (cells A, B, C)

A considerable amount of studies included in our review are about transferring technologies developed at universities or comparable research institutes into commercial organizations. In the last decades universities have significantly expanded their technology commercialization activities. Besides the traditional role of educating and doing basic research, this new role of universities is sometimes referred to as the "third mission" of universities (Rothaermel et al. 2007; Link and Scott 2010). They include licensing of patents, corporate partnerships, and the creation of spin-off companies (del Campo et al. 1999; Fini et al. 2010; Kroll and Liefner 2008). In accordance with Table 2, we distinguish between three main types. The first type is represented by cell (A) and stands for different forms of university-industry cooperation for technology commercialization objectives. The second type, represented by cell (B), discusses entrepreneurial activities of university scientists in a form of spin-offs. The last type is represented by cell (C) and describes the case when the university or federally-funded research institute is both the technology and the market party. This channel is, however, less studied than the first two types.

In the last years the collaboration of universities and industry has constantly increased (Caloghirou et al. 2001). From the companies' perspective this is mainly due to two reasons: The universities' higher willingness to license technologies and the nature of research, which is targeted more specifically towards industry requirements (Thursby and Thursby 2003). Companies also cooperate with universities to gain research synergies and broaden their knowledge in scientific research related to their field of operation (Caloghirou et al. 2001).

While university-industry collaboration is increasing, it is often mentioned in the literature that the absence of a mutual understanding between universities and industry causes difficulties (Siegel et al. 2003). In general, technology transfer from university to industry can be informal or formal. Informal mechanisms include linking students with industry (Boardman and Ponomariov 2009) non-contractual contacts (in both directions) with industry professionals, for example, at conferences, or joint research publications (Boardman and Ponomariov 2009; Grimpe and Fier 2009). Formal technology transfer mechanisms are usually research agreements defined by contracts (D'Este and Patel 2007), such as patenting and licensing contracts (Thursby and Thursby 2003).

Licensing of university technologies to large, established companies can be viewed as the traditional way of commercializing technologies (Powers and McDougall 2005b). In this case, technology transfer offices play a major role. However, in recent decades more channels for commercializing university technologies have emerged. In addition to the possibility of selling or licensing, which is sometimes referred to as the most frequent form of technology commercialization, there might also be consulting activities, joint publications or cooperative research (Radosevich 1995).

A considerable amount of papers that correspond to cell (A) are studies that examine this phenomenon from the university's point of view. Thursby and Thursby (2001), however, approach their research from an industrial perspective. They conducted a survey in order to assess how licensing executives from industry identify which technologies developed by universities might be of interest to them.

Another form of commercializing technologies which were developed at universities or other government-funded research institutes is through the creation of spin-off companies (Cell B). Although slightly different terms for this specific form of organization are used in the literature (e.g., (academic) spin-offs, (academic) spin-outs or university-based/academic startups), they all focus on newly founded companies that arise from a parent company or organization (Carayannis et al. 1998; Steffensen et al. 1999). We refer to spin-offs either when universities and research institutes represent the mother organization or when established companies take the role of the holding. The focus of this section lies on the first. The case when the parent organization is represented by an established company is discussed later.

Spin-offs represent one specific form of technology transfer since they are usually founded with the purpose of commercializing technologies that were developed at government funded laboratories, universities or private research organizations (Rogers et al. 2001). Smilor et al. (1990) defined spin-out companies in two different ways. On the one hand, they are companies which were founded by academic scientists, university staff or graduate students who have either left university or are still a member of it. On the other hand, the technology that was developed at the university might build the basis for the founding of the new firm.

Rogers et al. (2001) highlight the importance of this form of technology commercialization and Swamidass (2012), for instance, argues that—due to the higher risk that is associated with the university technologies—they may not get licensed by established firms

and are better suited for spin-offs. Despite claims that the latter might be true, we have shown in the previous section that there are established companies that do license-in university technologies. However, Chang et al. (2009) claim that it is difficult to license university technologies because of their tacit nature. Kroll and Liefner (2008) studied spin-off creation in Chinese universities and highlighted this form of commercializing technologies as the only option in regions where there is no legal system of patenting and a lack of trust between cooperating partners.

The creation of spin-off companies often occurs when the developing organization has identified that there is no initial market for the technology or when the companies in the market are not able to utilize the new technology (Hsu 2005). Thus, spin-offs typically try to enter market niches and their target markets are, hence, quite small (Autio 1994). The implementation of such innovations should take place in a fast and safe manner. This can be best achieved by getting those people involved who best know the technology, i.e., by personnel from the research organization that participated in the development of the technology (Hsu 2005; Radosevich 1995).

Cell (C) in Table 2 describes the case of a university or another government-funded research organization which represents both the technology-generating organization and the institution that aims to commercialize the newly developed technology. However, we could only find one scientific paper that researched this specific kind of interaction. Galbraith et al. (1991) studied the factors that affect the successful transfer of technologies from either private sector technology generators or from federally funded research institutions to public research institutions (Navy R&D centers). We believe this kind of interaction is mainly represented by governmental institutions as the market party and less by universities. The latter seem not to enter (or at least with only very rare exceptions) large scale markets with products that incorporate embryonic technologies that were developed within their organizations. A possible explanation for this might be that the technologies developed at universities are too basic and the university organization itself is too far away from the marketplace to be able to successfully commercialize the technology on its own.

4.2 Technology startups as technology developers (cells D, E, F)

Technology startups, new technology ventures (NTVs), or new technology-based firms (NTBFs) are small and usually young companies involved in innovation activities. In contrast to university spin-offs (cell B), technology startups develop their own technology. In the majority of these cases, the startup is even founded with the intention of developing technologies. The key characteristics of startups (young age and small in size) may imply that they are not very experienced in the potential market they might enter with their technology (Gans and Stern 2003).

New technology-based companies emerge not only from academic environments, for instance as university spin-offs, but also can be founded independently, meaning without any direct link to universities or research institutes. This does not imply that the managers of such companies do not have any previous connection to a university. These entrepreneurs often hold a university degree. Ensley and Hmieleski (2005), for example, studied differences and similarities between university spin-offs and independent startups, and found that around 45 % of the independent startup founders or managers hold a bachelor's degree. In other words, the top management of the technology startups as they are discussed in this section might have academic backgrounds, but do not have a connection to higher education institutions.

Similar to universities and other federally-funded research institutes as technology developers, these firms have different possibilities of commercializing their technology (Ceccagnoli and Hicks 2013). As represented by cell (D) in Table 2, they can, just as universities, sell or license their technology to established companies in the market. Another possibility they might consider is to enter the market with their own technology, as it is indicated by cell (E). Furthermore, as cell (F) represents, they might also be spun-in into governmental agencies.

An important line of research within the context of startups focuses on the composition of founding teams and the characteristics of the individual founders. This includes studies about the size of the founding team, their background and experience as well as the functional skills of the founders and the influence of these factors on the success of the startup and its technology.

The method and searching process we applied revealed only one paper that deals with spin-ins from technology startups to federally-funded research institutions. Thus, our study confirms the statement of Galbraith et al. (2004) who note that the transfer of technologies from the private to the public domain represents a neglected research stream. The paper by Galbraith et al. (2004) examines different factors that might lead to a spin-in of bio-defense technologies from small bio-technology firms to governmental agencies. Similar to other interaction modes, where technologies are transferred from the public to the private sector, they found that networking and personal contacts are the most important factors. On the individual level, conference presentations are ranked as the most valuable factor. Nevertheless, we need to emphasize that these results are derived from only one study and further research needs to be conducted to reveal more literature studying this interaction mode.

4.3 Established companies as technology developers (cells G, H, I)

In this section we focus on companies with an established position in one or more markets and internal technology research and development capabilities. We now discuss the situation displayed in the third row of Table 2, where an established company represents the technology party.

Different channels exist through which established companies can commercialize the technologies developed in their own laboratories. These include their own market entry (which usually involves further development of the technology), the patenting, and licensing of the intellectual property to other established companies or government-funded research institutes as well as the founding of new organizational units. We focus on situations where the company is not commercializing the technology by itself. This situation often occurs when the technology does not fit the strategic focus of the firm. Anokhin et al. (2011) refer to this as commercialization of misfit technology.

The development of new technologies represents a particular form of basic research. R&D in a company's own laboratories is expensive and involves high risks (Holden and Konishi 1996). Typically, companies that are engaged in this type of research view the money spent on such projects as long-term investments with a high uncertainty of them ever generating profits (Rosenberg 1990). Thus, the expectations about future cash flows resulting from such risky and usually large investments heavily influence the decision of companies to engage in technology commercialization (Nerkar and Shane 2007), and the decision on which channel to use for commercialization is an important strategic choice (Haeussler 2008). Therefore, companies must thoroughly evaluate which strategy to choose for bringing their internally developed technologies to the market.

Cell (G) in Table 2 represents the situation where an established company either enters the market with its own technology or interacts with other established firms to bring its technology to the marketplace. In order to increase the likelihood of profits generated by those uncertain inventions, some authors suggest incorporating the newly developed technology in different geographic markets and in a wide range of products (Nevens 1990). The latter is consistent with the findings of Rosenberg (1990). As he observed, the diversity of products is one reason why bigger companies are more likely to be involved in embryonic research as compared to small firms. A good example is 3M, whose diverse products are based on many different core technologies and which has the reputation of being one of the world's most innovative firms (Conceição et al. 2002). The high flexibility required reacting quickly to changes of different sorts, which is generally more associated with startups or spin-offs, can be achieved in large companies by giving its divisions a high autonomy (Conceição et al. 2002).

There are several reasons why some technologies have not been commercialized yet. Grimpe (2006) argues that certain factors associated with the organizational structure of the company influence the degree of non-commercialized technologies. He claims that, due to size and resource effects, larger companies have more non-commercialized technologies than smaller organizations. Because of the wide distance to the market, the same is also true for central research departments. The type of technology also plays an important role. Applied research seems to produce less non-commercialized technologies. He suggests the establishment of an internal, though independent, business unit that ensures commercialization of the technologies by spinning-in or spinning-out.

As indicated by cell (H) in Table 2, established companies might also commercialize their technology by spinning-off parts of the company and enable these business units to operate as independent new ventures. This is often the case when the innovations developed at the parent organization do not fit the current business strategy of the company (Wallin and Lindholm Dahlstrand 2006).

The interaction that is represented by cell (I) in Table 2 deals with the case when established companies as the developer of the technology cooperate with universities or other federally funded research organizations, which then bring the technology to the

	Commercialization channels									
Success factors and antecedents	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**Sum**
Industry closeness	4.5	2.3		0.3	0.3	0.5				*7.8*
Innovation culture	3.0	1.3		0.5	0.4		1.9	0.5		*7.6*
Intermediaries' support	4.3	3.6								*7.9*
Management techniques	1.9	1.6		1.7	1.1		4.3	1.6		*12.3*
Networking actvities	1.3	0.3			0.6	0.5	2.9	0.1		*5.7*
Property rights	3.2	2.4		0.3	0.6		0.1	0.1	0.5	*7.2*
Researchers' individual characteristics	6.8	2.3	0.7				1.0			*10.7*
Resource availability	2.0	2.8		1.7	1.9		0.1			*8.4*
Team structure	1.5	3.2		0.5	1.5		0.5		0.5	*7.7*
Technology application value	0.4	1.5	0.3	0.4	1.3		3.6	0.4		*7.9*
Technology suitability	2.9	1.8		0.5	1.8		0.7			*7.6*
Technology transfer strategy	6.9	7.1	0.5	2.6	4.1		4.8	1.5	0.5	*28.1*
University policy and structure	8.6	11.8			0.5		0.1			*21.1*
Sum	*47.2*	*42.0*	*1.5*	*8.4*	*14.1*	*1.0*	*20.0*	*4.3*	*1.5*	*140.0*

Fig. 3 Success factors and commercialization channels. *Note*: Numbers in the table are fractions of papers which research a specific success factor in the context of a specific commercialization channel

market. With regard to the market party, this situation can be compared to the situations in cells (C) and (F). As it was the case there, here again we could only find one paper focusing on this interaction (Caerteling et al. 2008). Hence, for all situations where the market party is represented by governmental institutions further research is required in order to give meaningful results for the interaction modes.

5 Antecedents and success factors of technology commercialization

A considerable amount of literature has been published on factors and settings which support the commercialization of technologies. An overview of the factors identified by the studies we reviewed, are presented in Fig. 3 and are further discussed in the following

Table 6 Coded factors

Final factor	Initial factors
Industry closeness	Geographical closeness, type of company, cultural barriers, industry orientation, type of research
Innovation culture	Innovation models, roles of champions, strategy for disruptive innovation
Intermediaries' support	Incubation policies for overcoming obstacles, Incubator availability, Proof of concept center availability
Management techniques	Capability to create product concepts, human capital, incentive structure, integrated roadmaps, management of external licensing, market research, organization design, priority on technology market matching, reward structure
Networking activities	Academic networks, alliance building, communication distance, contact between staff and academic researchers, intra firm networks
Property rights	CEO ownership, fairness of property rights distribution, patent availability, patent scope
Researchers' individual characteristics	Commercialization capability, faculty quality, marketing skills, motivation, risk taking aptitude, nationality, star scientists, time allocation, willingness to engage in transfer, age of scientist, gender of scientist
Resource availability	Access to finance, access to incubators, funding at university, internal human and technology based manufacturing sources, venture capital availability
Team structure	Prior joint experience, team completeness, team size, team compositions
Technology application value	Customer satisfaction, product development time, technology assessment, technology carve-outs, technology complexity, technology importance, technology radicalness
Technology suitability for commercialization	Age of innovation, competition in target market segment, development stage of technology, expected time to market, innovation scope, projected market share, pioneering nature
Technology transfer strategy	Early stage impediments, experimenting with technology in value networks, choice of strategy, innovation strategy, overcoming bottlenecks, project management of the transfer
University policy and structure	Autonomy of technology transfer office, degree of support, entrepreneurial orientation, design of process, quality of research, number of researchers, university size, organizational ambidexterity, type of university, previous spin outs

section. Some of these studies contained explicitly formulated antecedents of technology commercialization success, or a similar construct. Additionally, it is necessary to emphasize that technology commercialization is a very complex process and its success is dependent on many different factors. Therefore, papers may frequently also name a number of factors. It is not sufficient to concentrate on just one of these factors (Conceição et al. 2002), but the combination is important. In our sample we found that, for example, "University policy and structure" and "Intermediaries" are frequently researched together. Similarly, "Technology transfer strategy" and "Management techniques" are often researched in one paper. Due to the interaction of several factors and the differences between the various commercialization channels the order of the identified success factors represented in this chapter is concerned with readability and not importance.

The initial factors which we took from the studies in our sample are based on very specific settings and environments (some of which are derived from single case studies). Although, our aggregation will ease some of the contingencies and create a bigger scope, caution in generalization is required. We will now first explain the antecedents and success factors which we found. Table 6 gives an overview about the factors we initially found in the papers and how we coded them to our factors. In Fig. 3 we show how the different factors are related to the commercialization channels.

The first factor of technology commercialization we named University policy and structure. Under this factor we coded papers which contain research on what policies and organizations make universities stronger in terms of research commercialization. Some examples are organizational ambidexterity in universities or the development of dedicated commercialization processes. For a successful commercialization of university technologies, for example, an entrepreneurial orientation of the university seems necessary (Wong 2007). This can be fostered through entrepreneurship courses for students (Maia and Claro 2013; van Geenhuizen and Soetanto 2009; Wong 2007) or access to advice and coaching (van Burg et al. 2008). A properly designed study program that encourages technology development and innovation also seems to increase the number of spin-offs (Åstebro et al. 2012). The conflicts of interest that arise through cultural differences can be prevented through the creation of a dual structure that clearly distinguishes between the academic environment and industry (Argyres and Liebeskind 1998; Rasmussen and Borch 2010; van Burg et al. 2008). The type of university in terms of its history (i.e., traditional university or more recently founded) appears to have no influence on university-industry collaboration (Azagra-Caro 2007). However, the quality of university research does positively affect the rate of spin-off formation (Di Gregorio and Shane 2003; Link and Ruhm 2009). There is also evidence that success stories of previously conducted technology transfers through spin-offs from a particular university increases the rate of new ventures spinning-off from that university (O'Shea et al. 2005). Similarly, universities with previous experience in university-industry cooperation have higher TC involvement rates than other universities (Arvanitis et al. 2008).

The next factor we looked at, was the Researchers individual characteristics. This factor relates to personal attributes and demographics of researchers who engage in technology commercialization. Examples are the aptitude to take risk, network, or to take other action which aids technology commercialization. These types of study often also include research on demographics like gender, age, and nationality. Golish et al. (2008) found that there are significant differences between inventors with an academic versus an industrial background in how they approach the commercialization process. For the disciplines of engineering, economics/management or natural sciences and medicine, the involvement of scientists in TC is higher than for mathematics or physics (Arvanitis et al.

2008). The motivation of a researcher to engage in technology commercialization is not purely financial but in the first place usually related to conducting successful research and, hence, receive academic reputation in their research field (Colyvas et al. 2002; Siegel et al. 2003). The motivation for academics to engage in spin-off formation are similar to those of academics involved in licensing activities, i.e., it is rather about contributions that might advance their research, than financial returns (D'Este and Perkmann 2011). However, incentives do matter. At universities technology commercialization success could be increased by properly designed incentive systems addressed at both researchers and TTO staff (Siegel et al. 2003). On the other hand, the market party can increase commitment by granting rewards for its personnel in case of a technology being successfully transferred (Galbraith et al. 1991). This can be accomplished by offering quicker promotion possibilities or other financial rewards. Demographics and experience also have an effect on technology commercialization. Older academics are less contacted by industry, but more often publish papers together with scientists from industry (Boardman and Ponomariov 2009). Faculty quality in terms of research output also positively affects the rate of spin-off formation (Powers and McDougall 2005b). Spending more time on teaching has no effect on the likelihood of university scientists to engage in commercialization (Libaers 2012). This is in contrast, though, to the results of Arvanitis et al. (2008) who found that research institutes with a lower commitment to teaching are usually more engaged in technology transfer activities.

The Property rights describes the possibilities for the developer of a technology to protect the research through patents, and or the ability to obtain property rights of the new technology. Examples are studies which focus on the different outcomes of commercialization depending on the possibilities to protect technology and what entity or person becomes the owner of the technology. As described above in the research method, we tried to avoid papers which had a focus on patenting. However, we did find some papers where property rights came up as one of the factors. Colyvas et al. (2002) find that especially for embryonic technologies, university ownership of the technology facilitates technology commercialization. With more advanced technology intellectual property (IP) rights are less important. Shane and Stuart (2002) found an increase in licensing of university technology when technology is protected by patents. Li et al. (2008) find that CEO ownership of the technology increases commercialization success. A wider scope of patent protection, for example, increases this probability due to the broader application possibilities and the decreased likelihood of the technology being imitated (Nerkar and Shane 2007).

The factor Technology suitability for commercialization relates to attributes of the technology itself which support or hinder its commercialization. These are the factors like the quality of the technology, age, scope, pioneering nature, and expected time to market. This factor also relates to research on how the different sources of technology (e.g., university, research institute, industry) impact technology commercialization outcome. A frequently mentioned attribute in this category is that more applied research leads to higher rates of technology commercialization (e.g., Arvanitis et al. (2008)). The main reason for this is believed to be the higher marketability of technologies derived from applied research. There is no agreement about which design of the technology development process leads to a successful commercialization of the technology. While Eldred and McGrath (1997a) suggest a separate process which is not integrated into the product development process, Duhm and Wielockx (1991) state that a gradual technology development process and a close interaction with the production department provide a sufficient basis for successful technology commercialization. Excluding companies which rarely license-in, about

one-third of the firms reported that the characteristics of university technologies are the main reason for not licensing-in technologies developed at universities. They are either too fundamental or do not fit the strategy of the company (Thursby and Thursby 2001, 2003). Imitation can also be prevented by commercializing extremely innovative technologies (Nerkar and Shane 2007). Extremely innovative technologies are, however, embryonic and a lot of university technology managers believe that it is not possible for the licensing company to do the further development on its own. Instead, it can only achieve commercial success when the inventor of the technology participates in the further development of the technology (Jensen and Thursby 2001) and, thus, contributes to the success with highly specialized know-how (Thursby and Thursby 2003).

Under the factor Technology application value we summarized papers which contain research about how the identification of the potential value of new technology for a customer or user impacts the success of commercialization. Included are themes like the functionality of the technology and its alignment with users' requirements. Also included is research about how information on the application value is gathered. Market orientation and understanding the customers is seen as the key factor for successful commercialization; this means for the technology party to identify manufacturers (i.e., the market party to cooperate with) and for the market party to identify its end customers (Roberson and Weijo 1988). The incorporation of the requirements of the users of the technology when choosing new R&D projects have a positive impact on technology transfer success (Galbraith et al. 1991). This is the case for academic spin-offs (Roberson and Weijo 1988) as well as established companies that enter the market on their own (Slater and Mohr 2006). Slater and Mohr (2006) argue that the degree to which a firm can successfully commercialize technological innovations is dependent on the link of the company's strategy and both its ability to select a suitable target market and the level of market orientation. Therefore, the ability to identify appropriate target markets also supports the successful commercialization of technologies (Roberson and Weijo 1988; Slater and Mohr 2006). Identifying emerging markets increases the likelihood of the startup to grow in terms of sales turnover (Eisenhardt and Schoonhoven 1990).

Under the factor Team structure we coded papers which contain research about how the size, completeness, and background of teams working on technology commercialization impacts technology commercialization. Background refers to previous industrial or entrepreneurial experience, skills in marketing and management, and technology focus. Eesley et al. (2013) studied the composition of startup founding teams in different business environments: In competitive TC environments founding teams should be diverse. However, when the startup pursues an innovation strategy and is set in a cooperative environment, uniform and technically focused teams perform better (Eesley et al. 2013). Similarly, having a complete founding team (i.e., having the key positions filled) also contributes to the success of a startup (Roure and Keeley 1990). Prior joint experience as well positively affects the success of a new company (Eisenhardt and Schoonhoven 1990; Roure and Keeley 1990). Eisenhardt and Schoonhoven (1990) argue that founders with diverse industry experience, meaning some members have extensive experience and others only little, do also positively affect growth rates of the startups. Jensen and Thursby (2001) found that the university researcher needs to be involved in the further development of the fundamental technologies in order to successfully commercialize the technology he or she developed. A high faculty quality leads to both higher spin-off rates (Di Gregorio and Shane 2003; O'Shea et al. 2005; Powers and McDougall 2005b) as well as a higher involvement in technology commercialization activities in general (Ambos et al. 2008). The quality of the academic staff is more important than the quantity when it comes to

spinning-off companies (O'Shea et al. 2005). Students with an entrepreneurial interest and academics who have industry experience facilitate the creation of university spin-offs (Rasmussen and Borch 2010). Especially the latter can substantially support the commercialization of new technologies with their market contacts and with their ability to think like the customers of the spin-off, as they took this role earlier in their lives (Rasmussen and Borch 2010).

The TECHNOLOGY TRANSFER STRATEGY factor is associated with research on how the selection mechanism and transfer mode for the technology impact the commercialization outcome. Examples are models of technology commercialization, measurement scales for technology, and the choice of the commercialization method (e.g., licensing, patenting, spin-out, alliance). This factor also contains research on how different structures within new ventures impact the technology commercialization outcome. Gans and Stern (2003) argue that startups can either engage in cooperative commercialization activities with incumbent firms or choose to compete with those companies. The first case is the better solution when the protection of intellectual property is strong. Weak protection, in contrast, leads to competition. In their study of the status-quo of technology commercialization practices Kumar and Jain (2003) identified factors that influence the decision of new technology ventures to commercialize their technology. The most relevant parameters included the status of the technology, the source of the technology and the market potential for the end product. Another research area addresses the issue of commercialization processes. Companies which are successful in transferring their technologies into marketable products usually think of technology commercialization as a "highly disciplined system rather than a series of separate steps" (Nevens 1990, p. 155). This is in contrast to the reports of (Duhm and Wielockx 1991) who note that technology transfer is most effective when it is conducted step-by-step.

The factor INDUSTRY CLOSENESS relates to how the geographic, cultural, or network proximity of industrial firms to technology developers impacts technology commercialization. This includes research on regional characteristics but also on the research and industry orientation of universities. There are several success factors with relevance to the transfer between universities and large, established companies. Based on Rothwell (1989), Radosevich (1995) lists sufficient technical capacity, market strength, and existing links to key business partners as advantages of established companies when it comes to technology commercialization. The performance, growth rate and age of the companies close to technical universities do not differ from those of more general universities. But patent activities of companies located near universities with a technical background are slightly higher (Audretsch and Lehmann 2005). The research discipline, though, seems to have an impact on the rate of university-industry interactions (Bozeman and Gaughan 2007) and the engagement of academics in the transfer of technologies (Arvanitis et al. 2008; Azagra-Caro 2007). Likewise spin-off activities differ depending on the discipline. O'Shea et al. (2005), for instance, found that universities receiving funds for life science, chemistry, or computer science are more likely to create spin-offs. This can also explain the differences in the importance of different technology transfer channels (Bekkers and Bodas Freitas 2008). Reversely, there seems to be no evidence that the industrial sector to which the technology will be transferred has a significant impact on the commercialization of technology (Bekkers and Bodas Freitas 2008).

The factor RESOURCE AVAILABILITY includes research on how the availability of resources for the commercialization project like funding, venture capital, suitable personnel, supporting structure (e.g., incubators) impact technology commercialization outcome. Although we have seen earlier that industry grants positively affect the interaction between

university and industry, they do not increase the likelihood of university researchers to found a company (Boardman and Ponomariov 2009).

The antecedent Management techniques summarizes research on how the application of methods such as risk management, defining technology champions, absorptive capacity, transfer capabilities, milestones, project management, knowledge management, and governance capabilities impact technology commercialization. Top-level commitment seems to be important as well and managers should be directly involved into the technology transfer process in order to ensure fast decision-making (Nevens 1990). The market party can also increase the success of TC by informally supporting its personnel to search for and utilize innovative technologies (Galbraith et al. 1991). Ceccagnoli and Hicks (2013) found that the likelihood of potential customers to license technologies from startups is higher when the latter has a high knowledge transfer capability in the industry of application. If the potential customers of the technology have a high absorptive capacity, the knowledge transfer capability is less important for licensing. Both internal and external manufacturing sources contribute to a successful commercialization of technologies (George et al. 2002). A strong and well-educated internal labor force helps facilitating the commercialization of new technologies. In fact, results show that such kind of human resources (HR) capabilities have a positive influence on the speed of technology commercialization, new product quantity, the radicalness of those products, and patents. While the first two were also positively influenced by external HR manufacturing capabilities, the latter two are negatively influenced by external HR manufacturing sources and a trade-off needs to be considered. In their examination of Sony's commercialization of laser diodes, Wood and Brown (1998) identified different managerial approaches that are supportive of a successful commercialization of nascent technologies. Among others, they found that a transfer of employees from the research department to the development team during the implementation stage facilitates technology commercialization. That way, the researchers are also—at least to some degree—accountable for the implementation of the technology.

The factor Innovation culture includes research on how the general environment, principles believes and values of an organization impact technology commercialization. This is often closely related to organizational change. For example, the willingness of each individual to actively look for new technologies is necessary (Galbraith et al. 1991). In addition, a strong commitment to the technology by the staff working at the market party supports a successful commercialization of technologies (Radosevich 1995). A clear communication of the common goals of universities and companies and a higher flexibility in negotiating TT agreements can help decrease cultural barriers (Siegel et al. 2003).

Networking activities relates to research which is focused on how networks within or between organizations enable technology transfer. Examples are research on integration into supply chain or support for intra-organizational knowledge exchange. Research showed that strong social networks that connect university researchers help to increase the output of technology commercialization (Casper 2013). Crossing organizational boundaries, personal contacts between the researchers in the companies and the researchers from universities are important for successful technology commercialization (Thursby and Thursby 2001, 2003). In the same manner, a strong and effective cooperation in the manufacturing stage, between engineers engaged in process development and those engaged in production is required (Wood and Brown 1998; Duhm and Wielockx 1991).

Intermediaries' support factor includes research on how intermediaries such as technology transfer offices, proof-of-concept centers, or other specialized firms and organizations help bridging the gap between a research and a commercial environment. A reason why companies might neglect to license technologies from government-funded research

institutes, are the costs associated with the searching for appropriate technologies and the low likelihood of finding technologies that fit the firm's strategy (Roberson and Weijo 1988). Intermediaries are there to help overcome such hurdles. The chance of being commercialized is higher for technologies derived from projects that are pursued in higher research institutes that have established a technology transfer office as compared to those that do not have such facilities (Ambos et al. 2008). Universities may struggle with working both academically and commercially. In order to prevent conflicts of interest and cultural bias, academic and commercial research activities should be strictly separated (Argyres and Liebeskind 1998; Rasmussen and Borch 2010; van Burg et al. 2008). Technology transfer offices can assist in setting up such a dual structure that helps to better distinguish between both activities (Ambos et al. 2008). However, Siegel et al. (2003) found that TTOs are often understaffed. Thus, in general, additional resources should be devoted to TTOs, e.g., there should be at least one full-time project coordinator (Autio and Klofsten 1998). Fryda (1989) argues that research teams that have skills from different disciplines can help to give solutions to complex problems that cannot be solved by only one discipline. In this area the TTO can support commercialization projects by providing a high flexibility of services. Contradictory results were found regarding the importance of the TTO's experience. While Ambos et al. (2008) found that a higher experience does not affect technology commercialization, (Powers and McDougall 2005b) state that more experienced TTOs have established better routines to better support technology transfer. In contrast, however, a greater range of TTO services seems not to affect the commercial outputs of research projects (Ambos et al. 2008).

6 Discussion of our findings

In Fig. 3 we see the commercialization channels and the success factors. To make the table easier to read we omit zeros and indicated higher numbers with darker shades of gray. The numbers in the table are the number of papers dedicated to a certain mix of commercialization channel and success factor. Like above, fractions occur because numbers are weighted depending on the number of channels and success factors reported in a paper (e.g., if a paper reports on two channels A, B and E each will have the weight 1/3). If it also reports on two success factors, "Team structure" and "Industry closeness" each factor will have the weight 1/2. Put together, the number of papers reporting on "Team structure" in channel A is equal to 1/2 * 1/3, therefore 0.1667). Numbers add up across the table to 140, because we did not code success factors for the three papers on intermediaries. These results are shown above. The sum of the columns displays the number of studies which researched each of the success factors. The factors "University policy and structure" and "Technology transfer strategy" are clearly the most researched in our sample. The other factors are more or less evenly distributed.

We find it interesting to see that in our sample „Intermediaries' support" was only researched in a university context. Companies which own shelved technology which they cannot or do not want to commercialized because it does not fit their strategy, could also profit from specialized institutions. Similarly surprising we find that property rights are a success factor that is strongly focused on the university channels. We also want to point out that the factor "Technology application value" seems under-researched. We would assume that especially in a university context this would gain more attention. An early understanding of what truly delivers value, could be a powerful argument for commercializing

the technology. Understanding customer value early on, will be a topic in the chapter to come.

As we already mentioned above the settings where a university or other governmental research institute would act as the market party are rarely mentioned in the research we found (C, F, I). This might be a worthwhile gap to inspect because there are some new technology, especially around computation and the internet which could be seen as common goods and therefore should rather be commercialized by a public institution.

7 Conclusion of the literature review

In this review we have shown that there is a considerable amount of studies on technology transfer and commercialization. By systematically reviewing this large body of literature, we were able to present characteristics of different commercialization channels between technology developers and organizations commercializing these technologies, and to identify factors that support the successful commercialization of technologies.

Given the heterogeneous nature of the research area, this literature review contributes in several ways to advancing the theoretical knowledge about the various ways through which technology commercialization can take place. Firstly, it helps researchers to achieve an overview of previously published studies focusing on technology developers and recipients as well as their interactions in order to commercialize newly developed technologies. Given the large and diverse group of journals the field spans, with the help of our commercialization channels matrix we were able to bring together a number of papers rooted in very different research outlets. This can be very helpful for researchers to consolidate theories and empirical findings which are spread over different fields. Our study illustrates the major research areas and helps to identify gaps in the literature. Secondly, it classifies and synthesizes the literature on technology commercialization and its success factors in a novel way by organizing it according to the proposed framework of technology commercialization channels as represented in Table 2 and, thus, discusses the literature within a different context and from a different perspective. Thirdly, we provide 13 antecedents and success factors of technology commercialization. All factors are defined, motivated, and substantiated by papers from our sample. The factors can serve as a starting point for future empirical work on technology commercialization.

In addition to these theoretical implications, this study also has practical implications. Our systematic literature review can serve as guidance for technology managers, on which factors and characteristics influence the successful transfer and commercialization of technologies, given the diverse channels of technology commercialization. This holds for both the technology managers affiliated with the technology developer organization and those affiliated with the institutions trying to commercialize the innovation. However, it may be especially interesting for technology developers at universities and technology startups which try to understand, given the success factors form this review and their capabilities, what path of commercialization is most suitable in their case.

In addition to the analysis on factors and channels we also looked at the age of publications in this field. As already stated above overall it is a rather young field with many publications from the recent years. Looking at our factors we found that technology transfer strategy, technology application value, and university policy and structure have, on average, the oldest publication years (1996–1998). Whereas team structure, intermediary support, and resource availability have the youngest publication years (2003–2004). This

seems to indicate a trend from research surrounding universities and strategic considerations to research on startups and cooperative commercialization.

This systematic review intends to give a comprehensive and unbiased overview of the current literature on technology commercialization. However, our study has a number of potential limitations. In our third search step, we looked only at the reference list of article which we already identified as relevant. We could have extended the literature review further by also including the articles which are citing these identified papers. This would have added more recent literature to the sample. Furthermore, the results of a systematic literature review are dependent on the quality of the data used in the primary studies that are included in the review (White and Schmidt 2005). We were not able to check the quality of the empirical studies included in our review. Certainly our coding also leaves room for dispute. We tried to describe our steps as transparent as possible, but of course we needed to use our judgment in some cases.

This study provides a fairly comprehensive picture of what is known from previous studies about technology commercialization and the different ways it can take place. The information gained from this review, however, has raised several questions for further research. In future empirical studies it would be interesting to investigate what magnitude of change of one of those factors is necessary to actually change commercialization outcomes. Moreover, little is known about the measurement of successful commercialization of technologies and, especially, the ability to compare these measures across the different modes of interaction. Future studies could work on a scale of technology commercialization success. This could be especially interesting in the starting phase of such project, when financial measures are not applicable yet. Additional research might explore the dynamic aspects of the technology commercialization. For example, researchers could examine which situations and factors lead to a change in the interaction mode. This is especially relevant because we found that most current studies are focused on the early phases of technology commercialization. Moreover, it would be interesting to research whether there are certain market or technology parties that are more likely to change their channel of commercialization during their lifetime. Lastly, but most important, we saw that there is much research in the early stage of technology commercialization, but not that much in the later stages. This may be a valuable gap to close. There is a lot of entrepreneurship advice from both academic and practitioner sources. However, often this advice is rather targeted at B2C applications, and advice like farther iteration of prototypes may not be viable.

Appendix: A Literature review table of papers

In this table we list all the papers which we reviewed. We report the author and date for the identification of studies, the journal, research questions, research type, samples characteristics, key findings, success factors, and entry in our matrix.

Study	Journal	Research type	Matrix
Aggarwal and Hsu (2009)	Strategic Management Journal	Database research	D
Ambos et al. (2008)	Journal of Management Studies	Survey	A/B

Study	Journal	Research type	Matrix
Ankrah et al. (2013)	Technovation	Case study	A
Anokhin et al. (2011)	Technological Forecasting and Social Change	Theory	E/H
Argyres and Liebeskind (1998)	Journal of Economic Behavior & Organization	Theory	A/B
Arvanitis et al. (2008)	Research Policy	Survey	A/B
Astebro (2004)	IEEE Transactions on Engineering Management	Survey	E
Åstebro et al. (2012)	Research Policy	Case study	B/E
Audretsch and Lehmann (2005)	Research Policy	Survey	A/B
Autio and Klofsten (1998)	Journal of Small Business Management	Case study	B/E
Autio (1994)	Technovation	Survey	B/E
Azagra-Caro (2007)	Technovation	Survey	A
Bekkers and Bodas Freitas (2008)	Research Policy	Survey	A
Bekkers et al. (2006)	Journal of Technology Transfer	Survey	B
Boardman and Ponomariov (2009)	Technovation	Survey	A
Bozeman and Gaughan (2007)	Research Policy	Survey	A
Bradley et al. (2013)	Journal of Technology Transfer	Database research	A
Breznitz et al. (2008)	Journal of Product Innovation Management	Case study	B
Brown et al. (1991)	Research Policy	Theory	A
Burrington (1993)	International Journal of Technology Management	Theory	A
Caerteling et al. (2008)	Journal of Product Innovation Management	Case study	I
Caloghirou et al. (2001)	Journal of Technology Transfer	Database research	A
Carayannis et al. (1998)	Technovation	Case study	B
Carayannis and Roy (2000)	Technovation	Case study	B/E
Carayannis et al. (1998)	International Journal of Technology Management	Case study	A/C
Casper (2013)	Research Policy	Database research	A/B
Ceccagnoli and Hicks (2013)	Strategic Management Journal	Database research	D
Ceccagnoli and Hicks (2013)	IEEE Transactions on Engineering Management	Database research	B/E
Chang et al. (2009)	Research Policy	Survey	A/B
Chang et al. (1999)	Technovation	Case study	A
Chen (2009)	Journal of Business Research	Survey	D/E
Clausen and Korneliussen (2012)	Technovation	Survey	B
Colyvas et al. (2002)	Management Science	Case study	A

Study	Journal	Research type	Matrix
Conceição et al. (2002)	Journal of Engineering and Technology Management	Case study	G
Conceição et al. (2012)	Technovation	Survey	B
De Luca et al. (2010)	Journal of Product Innovation Management	Survey	G/H
del Campo et al. (1999)	IEEE Transactions on Engineering Management	Case study	A/B
D'Este and Perkmann (2011)	Journal of Technology Transfer	Survey	A/B
D'Este and Patel (2007)	Research Policy	Survey	A
Devine et al. (1987)	Journal of Technology Transfer	Case study	A
Di Gregorio and Shane (2003)	Research Policy	Database research	B
Dorf and Worthington (1987)	Journal of Technology Transfer	Theory	A/B
Duhm and Wielockx (1991)	International Journal of Technology Management	Theory	G
Eesley et al. (2013)	Strategic Management Journal	Survey	D/E
Eisenhardt and Schoonhoven (1990)	Administrative Science Quarterly	Survey	E
Eldred and McGrath (1997a)	Research Technology Management	Theory	E/G
Eldred and McGrath (1997b)	Research Technology Management	Theory	E/G
Fini et al. (2010)	Research Policy	Survey	B
Frishammar et al. (2012)	Journal of Product Innovation Management	Survey	G
Fryda (1989)	Journal of Technology Transfer	Case study	A
Galbraith (2012)	IEEE Transactions on Engineering Management	Survey	A/B/D/E
Galbraith et al. (1991)	High Technology Management Research	Survey	C
Galbraith et al. (2004)	Journal of Technology Transfer	Survey	F
Galbraith et al. (2006)	Journal of Technology Transfer	Survey	A/B/D/E
Gans and Stern (2003)	Research Policy	Theory	D/E
George et al. (2002)	Journal of Business Venturing	Database research	B
Goldfarb and Henrekson (2003)	Research Policy	Case study	A/B
Golish et al. (2008)	Journal of Product Innovation Management	Expert interviews	A/B/D
Gredel et al. (2012)	Technovation	Case study	D
Grimaldi et al. (2011)	Research Policy	Theory	A/B
Grimpe and Fier (2009)	Journal of Technology Transfer	Survey	A
Grimpe (2006)	Technovation	Theory	G/H
Haeussler (2008)	Entrepreneurship Theory and Practice	Survey	D/E
Hall et al. (2001)	Journal of Technology Transfer	Database research	A
Hansen et al. (2000)	Harvard Business Review	Case study	A

Study	Journal	Research type	Matrix
Henderson et al. (1998)	The Review of Economics and Statistics	Database research	A
Heslop et al. (2001)	Journal of Technology Transfer	Theory	A/B/E/G
Holden and Konishi (1996)	Journal of Technology Transfer	Case study	G/H
Hsu (2005)	Technovation	Case study	A/B
Hunter et al. (2011)	Research Policy	Survey	A/B
Jelinek and Markham (2007)	IEEE Transactions on Engineering Management	Expert interviews	A/B
Jensen and Thursby (2001)	American Economic Review	Theory	A
Johnson (2008)	Technovation	Case study	Intermediaries
Kasch and Dowling (2008)	Research Policy	Database research	D/E
Kassicieh et al. (2002)	IEEE Transactions on Engineering Management	Survey	D/G
Kassicieh et al. (2002)	Technovation	Case study	B
Kollmer and Dowling (2004)	Research Policy	Survey	D
Kroll and Liefner (2008)	Technovation	Expert interviews	B
Kumar and Jain (2003)	Technovation	Survey	E
Landry et al. (2013)	Technovation	Survey	A
Large et al. (2000)	Journal of Technology Transfer	Survey	A
Lee and Win (2004)	Technovation	Case Study	A
Leitch and Harrison (2005)	R&D Management	Case study	B
Li et al. (2008)	Journal of Product Innovation Management	Survey	G
Libaers (2012)	IEEE Transactions on Engineering Management	Survey	A
Libaers (2012)	Journal of Product Innovation Management	Survey	A
Libaers et al. (2006)	Journal of Technology Transfer	Database research	B/E/H/G
Lo et al. (2012)	Technovation	Survey	G
Maia and Claro (2013)	Journal of Technology Transfer	Case study	A/B
Maine et al. (2012)	Technovation	Case study	E
Maine and Garnsey (2006)	Research Policy	Case Study	B/E
Markham et al. (2002)	International Journal of Technology Transfer and Commercialization	Theory	A/G
Markman et al. (2005)	Journal of Business Venturing	Expert interviews	A
Markman et al. (2005)	Research Policy	Expert interviews	A/B
Markman et al. (2009)	Journal of Management Studies	Survey	A/B
Mian (1997)	Journal of Business Venturing	Case study	B
Mian (1996)	Research Policy	Case study	B
Moncada-Paternò-Castello et al. (2003)	Technovation	Case study	A/B

Study	Journal	Research type	Matrix
Nerkar and Shane (2007)	Strategic Management Journal	Database research	A
Nerkar and Shane (2003)	International Journal of Industrial Organizations	Survey	A/B
Nevens (1990)	Harvard Business Review	Expert interviews	G
Nicolaou and Birley (2003)	Journal of Business Venturing	Theory	B
O'Shea et al. (2005)	Research Policy	Survey	B
Patton et al. (2009)	Journal of Technology Transfer	Case study	B
Powell (2010)	Technovation	Case study	H
Powers and McDougall (2005a)	Journal of Business Venturing	Database research	A/B
Rasmussen and Borch (2010)	Research Policy	Case study	B
Ray and Ray (2010)	IEEE Transactions on Engineering Management	Case study	G
Rice (2002)	Journal of Business Venturing	Case study	A
Roberson and Weijo (1988)	Journal of Technology Transfer	Theory	B
Rogers et al. (2001)	Technovation	Database research	A/B
Roure and Keeley (1990)	Journal of Business Venturing	Survey	D/E
Shane and Stuart (2002)	Management Science	Database research	A
Shane and Stuart (2002)	Management Science	Database research	B
Shane (2001)	Management Science	Database research	B
Siegel et al. (1995)	Industrial Management & Data Systems	Case study	G
Siegel and Phan (2004)	Journal of Engineering and Technology Management	Expert interviews	A
Siegel et al. (2003)	Journal of High Technology Management Research	Expert interviews	A
Slater and Mohr (2006)	Journal of Product Innovation Management	Theory	G
Smilor and Gibson (1991)	IEEE Transactions on Engineering Management	Survey	Intermediaries
Smilor et al. (1990)	Journal of Business Venturing	Survey	B
Snow et al. (2011)	Journal of Product Innovation Management	Theory	E/G
Spann et al. (1995)	IEEE Transactions on Engineering Management	Survey	A/B
Spann et al. (1993)	Journal of Technology Transfer	Survey	A
Steffensen et al. (1999)	Journal of Business Venturing	Case study	B
Stuart et al. (2007)	Research Policy	Survey	B/E
Swamidass and Vulasa (2009)	Journal of Technology Transfer	Survey	A
Swamidass (2012)	Journal of Technology Transfer	Case study	B

Study	Journal	Research type	Matrix
Tegarden et al. (2012)	IEEE Transactions on Engineering Management	Survey	G
Thursby and Thursby (2001)	Industry and Higher Education	Survey	A
Thursby and Thursby (2003)	Journal of Technology Transfer	Survey	A
Thursby and Thursby (2002)	Management Science	Theory	A
van Burg et al. (2008)	Journal of Product Innovation Management	Case study	B
van Burg et al. (2013)	Journal of Product Innovation Management	Case study	B
van Geenhuizen and Soetanto (2009)	Technovation	Case study	B
Wallin and Lindholm Dahlstrand (2006)	Technovation	Database research	H
Walsh et al. (2002)	IEEE Transactions on Engineering Management	Survey	E/G
Walsh (2012)	Technovation	Theory	E/G
Wong (2007)	Journal of Technology Transfer	Case study	A/B
Wood and Brown (1998)	Journal of Product Innovation Management	Case study	G
Xu et al. (2011)	IEEE Transactions on Engineering Management	Survey	A
Zahra and Nielsen (2002)	Strategic Management Journal	Survey	G
Zhang et al. (2009)	Journal of Technology Transfer	Survey	B
Zucker et al. (2002)	Management Science	Database research	A/I

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