Diss. ETH No. 23922

Managing the Commercialization of New Technologies: Essays on Venture Capital Financing and Entrepreneurial Strategies

A thesis submitted to attain the degree of

DOCTOR OF SCIENCES of ETH ZURICH

(Dr. sc. ETH Zurich)

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2016

Confidence is the feeling you have before you fully understand the situation.

Acknowledgements

First and foremost, I would like to thank my thesis supervisor Prof. Dr. Stefano Brusoni for giving me the opportunity to carry out the thesis project and for supporting me through all its ups and downs. The years spent preparing this thesis have not only enhanced my theoretical skills, but have also been an exceptionally enlightening and instructive period on a personal level. Throughout that time, Prof. Dr. Stefano Brusoni offered me his valuable help and encouragement and guided me on my academic journey. Second, I am also deeply indebted to my co-supervisor Prof. Dr. Pius Baschera for his pleasant cooperation, which even extended beyond his retirement. Third, I would like to thank Prof. Dr. Petra Schmid for chairing the examination committee for my doctoral exam.

Furthermore, I would like to express my deepest gratitude to the entire Technology and Innovation Management (TIM) team, including both current and former team members. The team has continuously maintained an open-minded working atmosphere that fosters the active and fruitful exchange of ideas and opinions. In this context, I would like to thank each person for their time spent giving me valuable feedback, all the way from rough initial research ideas up to final paper drafts. The feedback was incredibly valuable in helping me get my research on track and draft my manuscripts. Moreover, I would like to thank the many smart and inspiring colleagues from other research groups at the department, specifically my "personal trainers" Jan Ossenbrink and David Grosspietsch, not only for significantly enhancing my athletic performance, but also for countless chats on topics research-related and otherwise. I also would like to express my gratitude to colleagues from the Master Studies Administration (MAS), particularly Maria Murillo and Dr. Sonja Ripperger, for their cordial support. Furthermore, it has been my pleasure to act as Ph.D. supervisor to several masters students in the MSc and MAS study programs, each with their own unique characters and ideas.

Besides my time in the TIM group, it was also a pleasure to be part of the team organizing the »venture» startup competition in early 2015. In this context, I would like to thank the whole organizational team, particularly Dr. Lea Firmin, for making this such an interesting and exciting time. Furthermore, I offer my sincere thanks to Dr. Firmin and Dr. Silvio Bonaccio for granting me access to the startup database for conducting an important part of my doctoral research.

Zurich, October 2016

Abstract

How can companies commercialize academic research more effectively? Due to its huge social and economic relevance, this is an important issue in management research and managerial practice. Although much has been written about technology transfer, scientific inventors and also other actors often underestimate the difficulty of translating new scientific knowledge into marketable, commercially viable products and applications. Major challenges include identifying and evaluating a business opportunity, motivating individuals to pursue a commercial route, and, ultimately, finding a way to effectively turn the idea into a sustainable business.

This cumulative dissertation aims to enhance the understanding of this topic from different perspectives, and places its central emphasis on individual-level factors of key actors and on processes (or approaches) to enhance commercialization. The thesis draws on, combines, and expands several insights from entrepreneurship literature, as well as from technology evolution and signaling theory. The five papers contained in this thesis build on qualitative and quantitative methods as well as on descriptive analyses.

Specifically, the first paper asks, *What individual-level factors matter for academic scientists when choosing an entrepreneurial model to transfer scientific findings to industry through a new venture? And, based on these insights, how should academics be linked with existing entrepreneurial approaches?* The qualitative empirical results suggest that there is fundamental heterogeneity in scientists' attitudes towards their own entrepreneurial engagement. The author of this doctoral thesis developed a typology of three different types of scientists based on their views on, and experience of, engaging in university spin-off projects: First, academic researchers with concrete plans for (or even experience in) co-founding a new venture together with other members of the inventor team. Second, scientists who are indifferent to or even reluctant about venturing projects, instead regarding their mission as teaching, scientific publishing, and open science. Third, those scientists who are generally open to pursuing venturing projects based on their technological discoveries, but who lack the entrepreneurial capabilities or resources needed to bring them to the market. The different views on engaging in a new venture indicate the need to differentiate scientists according to these three types, to determine the appropriate approach. To this end, Paper 1 shows how these three types of scientists can be systematically matched to existing entrepreneurial models. The study concludes that the involvement of external entrepreneurs might be a very effective and as yet underutilized mechanism for fostering the commercialization of university-generated knowledge.

Paper 2 advances the general understanding of how groups of evaluators vary in their assessments of business opportunities in two very early phases: the initial business-idea stage versus the later business-plan stage. The paper is based on a comparative analysis of three stakeholder groups that are crucial to new ventures: entrepreneurs, managers, and investors. In particular, it addresses the research question:

How do individuals occupying different professional roles vary in their assessments as to what makes an attractive business opportunity? In particular, how may certain linguistic cues influence external actors' evaluation of a business opportunity during the earliest phases? The quantitative research study is based on a unique dataset of 693 business ideas and 379 business-plan proposals submitted to a nationwide startup competition held in Switzerland. Linguistic analysis reveals systematic heterogeneity in opportunity evaluations between individuals with different professional roles. However, this divergence mostly emerges at the later business-plan stage, and is important to consider once a venturing project has reached that stage. The study provides empirical evidence *that,* and the *extant* to which individuals' professional role makes them more sensitive to certain aspects of a given business-plan proposal. These findings have important implications for a wide range of actors—above all for (would-be) entrepreneurs, policymakers, and initiators of business idea/plan contests.

Papers three, four, and five approach the thesis's overarching research question from a technological perspective. Extant literature suggests that many science-based businesses need area-specific approaches to technology transfer. Thus, based on the example of "nanobiotechnology," these three papers analyze the extent to which new technology has found its way into business. Furthermore, they suggest a number of ways to enhance the commercialization process and utilize descriptive methods to elaborate on quantitative data on venture capital (VC) financing, patenting, and product revenue, as well as mergers and acquisitions (M&A). The results indicate that despite unequivocal basic scientific advancements, the conversion of nanobiotechnology research results into commercial products with significant economic impact is still hampered by the chasm between basic academic research and product development in corporations. These impediments could be overcome by closer collaborations between academic research institutes and private enterprises in order to strengthen knowledge transfer. Relatedly, there is a shortage of skilled and experienced people who can pick up academic research results, develop them further, and finally commercialize them. To this end, the fifth research article of this doctoral thesis closes with contributions to a novel business approach that aims to help new industries achieve commercial breakthroughs, while allowing research-focused startups to cooperate and compete with both established organizations and academic departments.

Zusammenfassung

Wie können Unternehmen die Kommerzialisierung von Ergebnissen aus der akademischen Grundlagenforschung effektiver gestalten? Aufgrund der grossen sozialen und wirtschaftlichen Relevanz ist diese Frage in der betriebswirtschaftlichen Forschung und Praxis von zentraler Bedeutung. In den vergangenen Jahren wurden zahlreiche Abhandlungen über den Technologietransfer von Universitäten in die Privatindustrie veröffentlicht. Doch trotz all dieser Publikationen wird sowohl auf Seiten der wissenschaftlichen Erfinder als auch von anderen Akteuren oftmals unterschätzt, mit welchen Schwierigkeiten es verbunden ist, die neuen wissenschaftlichen Erkenntnisse in wirtschaftlich nachhaltige Produkte und Anwendungen zu überführen. Zu den wesentlichen Herausforderungen gehören in diesem Zusammenhang das Erkennen und Bewerten einer Geschäftsmöglichkeit, die Motivation der einzelnen Personen selbst einen unternehmerischen Weg einzuschlagen, und nicht zuletzt auch die praktische Umsetzung von der Idee bis hin zu einem wirtschaftlich nachhaltigen Geschäft.

Das Ziel dieser kumulativen Dissertation ist es, die Forschungsfrage aus unterschiedlichen Perspektiven zu eruieren. Die Forschungsschwerpunkte liegen dabei auf individuellen Eigenschaften einzelner Akteure und auf Prozessen (bzw. Konzepten) um die Kommerzialisierung zu fördern. Die Dissertation baut dabei auf bestehenden Forschungserkenntnissen aus den Bereichen Unternehmertum, technologische Evolution sowie der Signaling-Theorie auf und kombiniert beziehungsweise erweitert diese Erkenntnisse an einigen Punkten. Methodisch basieren die fünf Forschungsartikel in dieser Dissertation auf qualitativen, quantitativen und auch deskriptiven Untersuchungen.

Der erste Forschungsartikel dieser Dissertation widmet sich folgender Frage: *Welche individuelle Eigenschaften von akademischen Forschern sind für die Bestimmung eines geeigneten unternehmerischen Konzepts zu berücksichtigen?* Und, basierend auf diesen Erkenntnissen: *Wie können akademische Forscher den bestehenden unternehmerischen Konzepten zugeordnet werden?* Die empirischen Ergebnisse dieser qualitativen Forschungsarbeit deuten darauf hin, dass sich die persönlichen Einstellungen von Wissenschaftlern hinsichtlich des eigenen unternehmerischen Engagements wesentlich unterscheiden. Auf Basis ihrer persönlichen Haltung und Erfahrung bezüglich Gründungsprojekten wurde im Rahmen dieses Forschungsartikels eine Typologie von drei Kategorien von Wissenschaftlern entwickelt: Die erste Kategorie umfasst diejenigen Wissenschaftler, die bereits konkrete Pläne (oder sogar bereits Erfahrungen) hinsichtlich Unternehmensgründungsprojekten zusammen mit anderen Mitgliedern ihres Forschungsteams besitzen. Eine zweite Kategorie umfasst Wissenschaftler, die einem Gründungsprojekt entweder desinteressiert oder gar ablehnend gegenüberstehen und ihre Aufgabe in der Lehrtätigkeit und im (freien) Veröffentlichen von wissenschaftlichen Erkenntnissen verankert sehen. Zwischen diesen beiden Extrempolen gibt es noch eine dritte Kategorie von Wissenschaftlern, die einem Unternehmensgründungsprojekt grundsätzlich

aufgeschlossen gegenüberstehen. Sie sind sich jedoch darüber bewusst, dass sie nicht über die notwendigen unternehmerischen Fähigkeiten und Ressourcen verfügen, um die Kommerzialisierung im Alleingang durchzuführen. Aufgrund dieser grundsätzlichen Unterschiede in den persönlichen Einstellungen von akademischen Forschern hinsichtlich ihres eigenen unternehmerischen Engagements erscheint es erforderlich, die Forscher bei der Bestimmung eines geeigneten Konzepts entsprechend differenziert zu betrachten. In diesem Zusammenhang zeigt der erste Forschungsartikel, wie Wissenschaftler auf der Grundlage der entwickelten Typologie systematisch zu den bestehenden unternehmerischen Konzepten zugeordnet werden können. Die zentrale Schlussfolgerung des Artikels ist, dass die gezielte Einbeziehung von externen Unternehmern eine möglicherweise sehr effektive, bisweilen jedoch weitgehend vernachlässigte Strategie darstellt.

Der zweite Forschungsartikel befasst sich mit der Bewertung von gegebenen Geschäftsmöglichkeiten durch verschiedenen Personengruppen. Die Analyse umfasst dabei zwei sehr frühe Phasen des Unternehmensgründungsprozesses: Die Phase, in der nur eine erste Geschäftsidee vorliegt und die etwas spätere Phase, in der bereits ein Geschäftsplan vorliegt. In diesem Zusammenhang wird im zweiten Artikel eine Vergleichsstudie anhand von folgenden drei wichtigen Interessengruppen durchgeführt: Unternehmer, Manager und Finanzinvestoren. Konkret untersucht der Artikel: *Wie unterscheiden sich die Bewertungen von gegebenen Geschäftsmöglichkeiten auf Basis der beruflichen Funktion des Begutachters? Welche Bedeutung spielen dabei bestimmte Stichwortkategorien bei ihrer Bewertung?* Die quantitative Analyse im zweiten Artikel basiert auf einem umfangreichen Datensatz bestehend aus 693 Geschäftsideen und 379 Geschäftsplänen, die anlässlich eines schweizweiten Gründungswettbewerbs eingereicht wurden. Wie die linguistische Analyse offenbart, gibt es systematische Unterschiede in der Bewertung, je nachdem, welche berufliche Funktion der Begutachter innehat. Statistisch signifikante Unterschiede zeigen sich jedoch meist erst in der Phase, in der ein detaillierter Geschäftsplan vorliegt – eine Erkenntnis, die es zu berücksichtigen gilt, wenn ein Gründungsprojekt dieses Stadium erreicht hat. Der Artikel liefert den empirischen Beweis dafür, *dass* und in welchem *Ausmass* sich die berufliche Funktion eines Begutachters auf dessen Sensibilität für bestimmte Aspekte in einem Geschäftsplan auswirkt. Die hier nachgewiesene Heterogenität der Bewertung in Abhängigkeit von der jeweiligen beruflichen Tätigkeit birgt wichtige Implikationen für unterschiedliche Akteure – allen voran für die (möglichen) Unternehmensgründer selbst, aber auch für andere Entscheidungsträger und für Organisatoren von Ideen- und Gründungswettbewerben.

Artikel drei, vier und fünf widmen sich der übergeordneten Forschungsfrage aus einer technologischen Perspektive. Wie frühere Studien belegen, gibt es für eine Reihe von wissenschaftsbasierten Geschäftsfeldern einen Bedarf an technologiespezifischen Strategien, um neue Technologien wirkungsvoll zu kommerzialisieren. Auf Basis dessen untersuchen die Artikel am Beispiel von „Nanobiotechnologie“, wie sich aus dieser neuen Technologie bereits neue Geschäftsaktivitäten entwickelt haben. Darüber hinaus zeigen die Artikel verschiedene Möglichkeiten auf, wie die Kommerzialisierung gezielt gefördert werden könnte. In den Artikeln wird dabei auf deskriptive Methoden zurückgegriffen, um quantitative Datensätze zu Wagniskapitalfinanzierung, Patenten, Produktumsätzen sowie Fusionen und Übernahmen zu analysieren. Die Forschungsergebnisse weisen darauf hin, dass—trotz der Fortschritte auf wissenschaftlicher/technischer Seite—die Kommerzialisierung bislang deutlich hinterherhinkt. Ursächlich scheint dieser Rückstand insbesondere in der tiefen Kluft zwischen akademischer Grundlagenforschung und der Produktentwicklung in der Privatwirtschaft begründet. Um diese Kluft wirksamer zu überwinden und damit einen effektiveren Wissenstransfer herzustellen bedarf es einer engeren Zusammenarbeit zwischen akademischen Forschungseinrichtungen und der Privatwirtschaft. Allerdings mangelt es an qualifizierten und zugleich industriell erfahrenen Personen, die in der Lage sind, die wissenschaftlichen Erkenntnisse aufzugreifen, weiterzuentwickeln und schliesslich an den Markt zu bringen. In diesem Sinne befasst sich der fünfte Artikel dieser Dissertation mit der Erarbeitung einer neuartigen Geschäftsstrategie. Diese soll so konzipiert sein, dass sie neuen Technologiebereichen zu ihrem industriellen Durchbruch verhilft und sie zugleich forschungsintensiven Jungunternehmen erlaubt, mit etablierten Unternehmen als auch mit akademischen Forschungseinrichtungen wahlweise in ein Kooperations- oder auch Konkurrenzverhältnis zu treten.

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ANOVA	Analysis of Variance
B	B Coefficient (Effect Size Coefficient)
Biotech	Biotechnology
CAGR	Compounded Annual Growth Rate
CEO	Chief Executive Officer
cf.	*conferre* (“compare”)
DII	Derwent Innovations Index
DNA	Deoxyribonucleic acid
e.g.	*exempli gratia* (“for example”)
et al.	*et alii* (“and others”)
etc.	*etcetera* (“and so on”)
ETH Zürich	Eidgenössische Technische Hochschule Zürich
FA	Founding Angel
FDA	(United States) Food and Drug Administration
i.e.	*id est* (“that is”)
ICT	Information and Communication Technology
IE	Inventor Entrepreneur
IP	Intellectual Property
IPC	International Patent Classification
IPR	Intellectual Property Rights
LIWC	Linguistic Inquiry and Word Count
M&A	Mergers and Acquisitions
Nanobiotech	Nanobiotechnology
Nanotech	Nanotechnology
NNI	(United States) National Nanotechnology Initiative
No.	number
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least-Squares
p	p-value
p.	page
pp.	pages
R&D	Research and Development
RQ	Research Question

SE	Surrogate Entrepreneur
SMEs	Small and Medium-sized Entities
TTO	Technology Transfer Office
U.S.	United States (of America)
US$	United States Dollar
USO	University Spin-Off
VC	Venture Capital
vs.	versus
ρ	Rho (Correlation Coefficient)

Synopsis

1. Introduction

1.1. The challenge: Turning ideas into a viable business

The wealth of modern societies is increasingly based on a widely accessible and continuously growing base of scientific knowledge (e.g. Robin and Schubert 2013; Freeman and Soete 1997; Rosenberg 1982; Nelson and Winter 1982). Nevertheless, in order to generate economic wealth, it is not sufficient merely to expand and disseminate scientific knowledge *per se;* such knowledge must also be translated into new goods and applications with commercial potential. Entrepreneurship is often considered to be one key mechanism to achieve this translation and, thus, to enhance economic development (Shane 2005a). This association is due to the fact that the commercialization of new technologies, scientific research results, or other innovative ideas is a key characteristic of entrepreneurship (Nelson 2014). The research subject of entrepreneurship includes the study of *sources* of (potential) business opportunities, as well as of *processes* and *individuals* involved in discovering, evaluating, and translating scientific or technological innovations[1] into marketable products or services (Shane and Venkataraman 2000).

With regard to the *sources* of (potential) business opportunities, Shane (2005b) points out that entrepreneurship is based on some form of innovation, although this does not imply that all entrepreneurial efforts require the ground-breaking innovations described by Schumpeter (1934)[2]. According to Shane (2005b), entrepreneurship can also be based on less radical forms of innovation, such as placing a restaurant at a transport hub, or altering recipes or replacing staff in a new restaurant at the same location as the old one. Nonetheless, the concepts of "entrepreneurship" and "innovation" have been strongly interrelated (Autio et al. 2014) in literature and practice. In recent decades, scholars as well as policymakers have increasingly focused on academic research institutions as sources for innovations with commercial potential, which could lead to economic growth and enhance regional development (Rasmussen et al. 2006; Wright et al. 2007).

Considering the second dimension of entrepreneurship research—*processes* to exploit the opportunity—one popular avenue for commercializing university-generated knowledge is the creation of university spin-offs (USOs) (Politis et al. 2012). USOs are defined as new ventures that have been initiated in a university setting and that are based on knowledge originating from a university or another academic research institution (Shane 2004; Rasmussen and Borch 2010; Rasmussen 2011). Besides licensing and patenting topics, USOs are a central pillar of the "academic entrepreneurship"[3] literature (Abreu and Grinevich 2013). The entrepreneurial approach of using USOs to master technology transfer has attracted significant attention from scholars as well

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1 de Jong (2013, p. 282) defines innovation exploitation "as recombining resources to actually create and introduce new products or processes."

2 Schumpeter (1934) famously described the "gales of creative destruction" that "entrepreneurs unleash by introducing new, radically different products, services, and processes to the marketplace, thereby challenging status quo-preserving industry incumbents" (Autio et al. 2014, p. 1097).

3 By analogy, "corporate entrepreneurship" refers to the exploitation of business opportunities emerging from a corporate setting through "corporate spin-offs" (e.g. Feldman et al. 2014) or "corporate spin-outs" (e.g. Cirillo et al. 2014; Franco and Filson 2006), respectively. See Madsen and Walker (2016) for the variance in these labels, including an attempt to classify the labels researchers assign to ventures initiated by employees of incumbent companies.

as policymakers (see Bozeman et al. (2015), Rothaermel et al. (2007), and Perkmann et al. (2013) for a review). In practice, there is often limited awareness and understanding of the different types of USOs that exist, leading to a tendency to consider USOs as largely homogeneous entities—e.g. when formulating policy implications (Politis et al. 2012). In this vein, various authors have called for more differentiated technology-transfer approaches, which put a greater focus on scientists' individual-level attributes (e.g. Clarysse et al. 2011; Lam 2011; Shane 2005b) and on strategies that enable scientists to better capitalize on their research discoveries (e.g. Hall et al. 2014a; Hall et al. 2014b; Dedrick and Kraemer 2015; Teece 1986).

These arguments bridge the transition to the third dimension of entrepreneurship research, namely *individuals*. In general, the exploitation of a business opportunity requires people with a variety of skills (e.g. in terms of technology, fundraising, business networks, and the operational setup and running of a new venture) and the motivation to become entrepreneurially engaged. Therefore, such exploitation is strongly influenced by people's social and institutional environment (Rasmussen et al. 2014), and typically necessitates a group that extends beyond the originator(s) of the business idea or technology.

In general, individuals and individual-level factors play a central role in the commercialization of new technologies; thus, they are particularly emphasized in this thesis.

1.2. The importance of individual-level entrepreneurship factors

While much has been written on transferring scientific research results from academia to business, the question of how to align entrepreneurial efforts with individual-level factors remains largely unexplored. For instance, in context of the creation of a USO, policies are often designed such that the academic scientist, as the originator of a new technology or business idea, becomes the (or an) entrepreneur (O'Shea et al. 2008; Radosevich 1995; Miner et al. 1992; Freeman and Soete 1997; Kenney and Patton 2009)—while neglecting the scientist's intrinsic motivation (Lam 2011) to become entrepreneurially engaged. In contrast, Politis et al. (2012) point out that only a few studies acknowledge the need for alternative approaches to the commercialization of university-generated knowledge—for example, by involving "external entrepreneurs" (e.g. Radosevich 1995; Franklin et al. 2001; Lundqvist 2014; Festel et al. 2015).

Another example where individual-level attributes have been neglected in entrepreneurship literature and practice is in the evaluation of the viability of a business opportunity by an external person (Williams and Wood 2015; Drover et al. 2015; McMullen and Shepherd 2006). In the context of third-person evaluations, Gruber et al. (2015) note that little is known about how the heterogeneity of people's professional and educational experience endowments affects their personal judgments/perception of the attractiveness of a given business opportunity. For external actors in particular, the evaluation of a new venture is *difficult* due to the lack of generally accepted evaluation schemes and verifiable information (Brush and Vanderwerf 1992; Gruber 2007; Shepherd et al. 2003). Compared to scrutinizing established companies and mature firms, determining the potential of a given business opportunity is even harder, since there is nothing to go on but a business idea—sometimes supplemented by a prototype or initial concept study. Drover et al. (2015) point out that the difficulty of assessing a new venture becomes especially salient in VC screenings. Here, VCs must quickly and efficiently discern which business opportunities are worth advancing to the due diligence process, since this process requires substantial resources to assess the respective opportunity properly (Chan and Park 2015; Kirsch et al. 2009).

Taken together, further enhancing the understanding of individual-level factors based on extant entrepreneurship literature (e.g. Fini et al. 2009; Rasmussen and Wright 2015; Clarysse et al. 2011) may contribute to developing more fine-grained managerial and policy implications, and thus support new venture founders and other external stakeholders (Rasmussen et al. 2014).

1.3. Research positioning

This thesis aims to investigate how to manage the commercialization of new technologies. In this context, it puts a particular emphasis on the role of individuals and related individual-level factors. The research is oriented along the three dimensions of entrepreneurship research proposed by Shane and Venkataraman (2000)—sources, processes, and individuals—with a particular emphasis on the last two: *processes* (or approaches) to manage commercialization and *individual*-level factors of people engaged in the technology transfer.

While I do not mean to imply that these dimensions are exhaustive, they do adequately reflect the overarching goal of this thesis: to provide a better understanding of how to commercialize scientific research results effectively.

To provide a comprehensive view of the subject, the thesis is structured into three topic areas, each with an individual focus on the overarching research question. While the first two topics are each addressed by one comprehensive scientific research paper, the third is covered by a further three practitioner-oriented articles, contributing to a more complete picture.

My research positioning is summarized in **Table 1**.

Table 1: Research positioning based on the three dimensions of entrepreneurship research

Topic area	Dimensions		
	Source	**Process**	**Individuals**
1	Academic research	USO creation	Scientific researchers
2	Wider entrepreneurship	New venture creation	External evaluators
3	Confluence of technologies	Business model innovation	Industry sector/firm level

Based on **Table 1**, I now describe my research positioning more fully, along the three dimensions of entrepreneurship research.

Sources: In all the research projects in this thesis, the technology and/or related individuals used as the unit of analysis are deeply rooted in a university or academic research setting (whether explicitly and/or implicitly). Thus, the research places a particular emphasis on university-generated knowledge as the *source* of new businesses. Whereas Topic 1 (**Table 1**) explicitly focuses on knowledge and new ventures emanating from academic institutions, in subsequent topics this narrow focus on universities as the source of the underlying technology (and the people originating the business opportunities) is gradually broadened out. In other words, following an initial tight focus on USOs, the scope progressively expands to encompass new venture projects that do not necessarily emerge from academia (although most do, given the research setting) (Topic 2). To supplement insights on the research question, the thesis finally switches to a more technology-based view (Topic 3). Here, the source of business opportunities is a specific technology area that, until now, has barely existed beyond basic academic research: nanobiotechnology[4]. Based on this example, I aim to investigate how to pave the commercial way for a new technological subject area.

Process: The thesis puts a strong research focus on the formation of USOs as the *process* (or mechanism) to exploit the (potential) business opportunities arising from academic research results. The focus is on related business or entrepreneurial approaches. Other commercialization efforts, such as licensing from universities or incubator/accelerator programs, are not covered. Besides entrepreneurial approaches (i.e. the USO process), the thesis examines how corporate strategies/business models should be adapted to commercially exploit research advances—based on the exemplary subject area of nanobiotechnology.

Individuals: Finally, the thesis considers the *individuals* necessary to bring business opportunities to market. I focus in particular on the influence of individual-level attributes on setting up a new venture from the perspectives of both sides: academic scientists and external evaluators (i.e. other entrepreneurs, corporate managers, and venture capital (VC) investors).

1.4. Research framework

Over recent decades there have been significant efforts in theory (e.g. Teece 1986; Bozeman et al. 2015; Perkmann et al. 2013) and practice (cf. Huggett 2014) towards making the commercialization of new technologies more effective. Building on these insights, the overarching research question that guides this thesis is:

Overarching research question:
How can companies make the commercialization of basic academic research results more effective?

[4] Maine et al. (2014a, p. 2) describe nanobiotechnology as "the application of nanotechnology to biological processes." Similarly, Paull et al. (2003, p. 1146) define it as "the interface of nanotechnology with biology. Alternatively, it may define any application of nanotechnology in biological research, drug discovery and drug delivery devices, diagnostic tools, therapeutics or novel biomaterials."

To address this question, I draw on qualitative, quantitative, and descriptive methods to approach the research question from three different angles, as presented in **Figure 1**: the perspective of the originator of a technology/opportunity with commercial potential; the perspective of other supporting actors, including key (serial) entrepreneurs, corporate managers, or VC investors; and from the perspective of an emerging technology. Based on the example of nanobiotechnology as an emerging technology, arising from the "confluence of two previously disparate research fields" (Maine et al. 2014a, p. 2), I examine the current obstacles to commercialization and derive managerial recommendations for overcoming them.

A key theme is building connections between the originators of the technology/opportunity and supporting actors—in this case, seasoned entrepreneurs from outside the university setting and external evaluators of a business opportunity (i.e. third-party entrepreneurs, managers, and investors). Such supporting actors have been referred to as "gatekeepers of resources" (Foo et al. 2005, p. 392), because convincing them that the business opportunity is viable is central to securing key resources, including financial capital, human capital, business networks (Birley 1985), and advice.

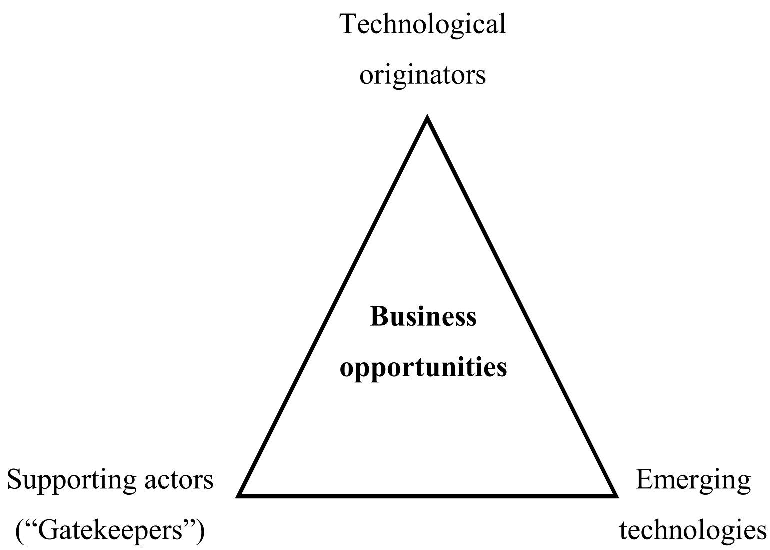

Figure 1: Overarching research framework

1.5. Links between the papers

The three dimensions of entrepreneurial research (Shane and Venkataraman 2000) provided the subjects analyzed *within* the individual research papers (as shown in **Figure 1** and **Table 1**). The overall structure of the thesis, in terms of the *connections* between the papers, draws on the staged process known as the "linear model of innovation."

According to this model, innovation follows an orderly process in which newly generated basic knowledge must pass through various stages before eventually reaching a final, viable form of practical output (Price and

Bass 1969). The starting point is basic research, followed by applied research and development, and finally production and diffusion (Godin 2006).

Seen in this light, the papers in this thesis correspond to central issues arising at different stages along the innovation process. Drawing on the simplistic representation of the innovation process emerging from the linear model, **Table 2** situates the individual papers along the life cycle of a company. Papers 1 and 2 focus on the very early stages of entrepreneurial venturing, while the technology-focused papers (Papers 3 to 5) are more closely related to products/companies at a more mature stage.

The topics covered in each individual paper are challenging for practitioners in themselves. However, effective commercialization requires the business opportunity to pass through *all* of them. Moving the opportunity from one stage to the next is another major challenge, reflected in the inter-phase research projects in Papers 2, 4, and 5 (**Table 2**).

In line with some criticisms leveled at the linear model[5], my empirical evidence seems to contradict the concept of a *linear* process. Only rarely do business opportunities clear all the challenges at one stage before passing on irrevocably to the next. Instead, the journey from basic scientific discovery to viable product is a dynamic, non-linear, and integrative process that is influenced by numerous individual-level and technology-specific factors. The challenge is not only to align these factors at one particular stage, but also to prepare the way for passing through the next—an endeavor to which I devote particular attention.

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[5] In innovation literature, the linear model of innovation has been much criticized (see Balconi et al. (2010) and Godin (2006) for a differentiated review) as an inadequate construct to explain the process between funding basic research on one hand and achieving practical outcomes on the other. Nevertheless, while some criticisms are warranted, the linear model is also built on some valid assumptions and it served as the basis to develop more recent and sustainable models that include a multitude of feedback loops in the revised process (Freeman 1996; Balconi et al. 2010; Etzkowitz 2006).

Table 2: Overview of the research across the stages of business venturing

<table>
<tr><th></th><th colspan="3">Seed stage</th><th colspan="2">Early stage</th><th colspan="2">Later stage</th><th>Mature stage</th></tr>
<tr><td>**Phase**</td><td>Discovery & recognition</td><td>Business idea</td><td>Business plan</td><td>Startup</td><td>First stage</td><td>Expansion stage</td><td>IPO; M&A; or strategic partnership</td><td>Post-IPO</td></tr>
<tr><td>**Principal tasks**</td><td>Technical research; opportunity recognition</td><td>Initial research on customer benefits and markets</td><td>Research on customer benefits; market studies; implementation plan</td><td>Incorporation; product development</td><td>Start of production; market launch</td><td>Physical plant expansion; product improvement</td><td>Preparation of exit or collaboration</td><td>Strategic realignment</td></tr>
<tr><td rowspan="2">**Entrepreneurial focus**</td><td>**Paper 1**</td><td colspan="7"></td></tr>
<tr><td></td><td colspan="2">**Paper 2**</td><td colspan="5"></td></tr>
<tr><td rowspan="3">**Technological focus**</td><td colspan="7"></td><td>**Paper 3**</td></tr>
<tr><td colspan="6"></td><td colspan="2">**Paper 4**</td></tr>
<tr><td colspan="8">**Paper 5**</td></tr>
</table>

The remainder of this dissertation is structured as follows: Section 2 provides an overview of the theoretical foundations, deriving the individual research gaps to be addressed. Building on these theoretical foundations, Section 3 presents data and methods used to examine the individual research questions. Section 4 summarizes the results of the four research papers. The dissertation closes with discussion and conclusion in Section 5, including implications for theory and practice.

2. Theoretical background and objectives

This chapter introduces the theoretical foundations underlying each individual paper, presented in a linear structure as described in Section 1.5 and depicted in **Table 2**. It starts with a research project on academic entrepreneurship at the very early stage—the phase when a scientist considers whether or not to initiate entrepreneurial endeavors. The chapter continues with another research topic at the next stage, when there already exists a rough outline of a venturing project (in the form of a business-idea proposal) or even a more concrete business plan of a venturing project that is to be launched. The research then switches to a technology perspective, and also jumps to technology-transfer topics relevant to established companies at a mature stage of development.

Table 3 presents a concise overview of the individual research objectives and research questions for ease of reference.

Table 3: Overview of topics, papers, and respective research questions

Topic area	PAPER		
	#	**Title**	**Research question**
I) Academic Entrepreneurship	1	*To each his own: Matching different entrepreneurial models to the academic scientist's individual needs*	*What individual-level characteristics matter when choosing an entrepreneurial model to transfer scientific findings to industry through a new venture? And, based on these insights, what is the best way to link academics with existing entrepreneurial approaches?*
II) General Entrepreneurship	2	*Is value in the eye of the beholder? An empirical study of how entrepreneurs, managers, and investors evaluate business opportunities at the earliest stages*	*How do individuals occupying different professional roles vary in their assessments of what makes an attractive business opportunity? In particular, how may certain linguistic cues influence external people's evaluation of a business opportunity during the earliest phases?*
III) Emerging Technologies	**3**	*Nanobiotech in big pharma: A business perspective*	*Has nanobiotech already taken hold as a significant addition to the intellectual property portfolio within the established pharmaceutical industry ("big pharma"), particularly in comparison to the established biotech field? Is big pharma already capitalizing on this new technological area?*
	4	*Sourcing innovation through M&A: Lessons from nanobiotechnology*	*How do established companies respond to the emergence of the nanobiotech industry? What is the role of startups and what business and R&D strategies should they pursue?*
	5	*Commercializing nanobiotech: Time to take stock*	*How can new industries achieve commercial breakthroughs, while developing an organizational model through which new entrants could cooperate and compete with both established organizations and academic departments?*

2.1. Academic entrepreneurship and the involvement of external entrepreneurs

Compared to entrepreneurship in a wider sense, academic entrepreneurship has certain distinctive features, due to its roots. In academic entrepreneurship, new ventures emerge from traditionally non-commercial university contexts. Under scientists' employment contracts, intellectual property rights (IPR) are often owned, at least in part, by the university that employs them (Siegel and Wright 2015).

Interest is growing in understanding the mechanisms of academic entrepreneurship (Jain et al. 2009; Louis et al. 1989; O'Shea et al. 2005; Shane 2004). Historically, the norms of open science—with its goal of publishing and broadly disseminating results—have dominated academic research. However, over the last few decades there has been a remarkable shift towards actively seeking commercial avenues to exploit research results (Jain et al. 2009; Owen-Smith 2005; Bercovitz and Feldman 2006; Wright et al. 2007). The technology transfer of academic research discoveries to commercial applications has been a popular topic not only for academic researchers, but—because of the associated economic potential—also among managers, entrepreneurs, investors, and policymakers. In many countries, governmental and university policymakers have made concerted efforts to foster the commercialization of university-generated knowledge (including patenting, licensing, and academic entrepreneurship). There are various reasons for these initiatives, ranging from generating societal legitimacy for publicly sponsored scientific research and stimulating regional/national economic activity to raising research funding for universities (Perkmann et al. 2013).

Rising interest and activity in terms of academic entrepreneurship has led to a proliferation of research studies (see Bozeman et al. (2015), Rothaermel et al. (2007), and Perkmann et al. (2013) for a review).

In the academic entrepreneurship literature, many studies have examined how Technology Transfer Offices (TTOs) can become generally more effective (Siegel et al. 2003; Weckowska 2015). In this context, effectiveness often denotes patenting, licensing (see Grimaldi et al. (2011) for a review), and providing operational support to entrepreneurial ventures once team formation is completed (Lockett et al. 2005).

Traditional models of technology transfer are mainly based on two distinct alternatives. The models assume that scientists prefer either to "go it alone" and become entrepreneurs themselves (the inventor-entrepreneur (IE) model) (e.g. Miner et al. 1992; Grandi and Grimaldi 2005; Di Gregorio and Shane 2003), or to release their technologies to others who are interested in their commercialization (the surrogate-entrepreneur (SE) model) (Radosevich 1995; Franklin et al. 2001). Alongside these two entrepreneurial models has recently emerged another, largely unexplored approach—the Founding Angel (FA) model. Here, the scientific inventor plays an integral part in the spin-off project from the outset and the FA acts as a co-founder together with the scientific inventor (Festel et al. 2015; Festel and De Cleyn 2013b). As the FA model implies the pairing of a scientist with a seasoned entrepreneur from outside the academic setting, this can be considered an intermediate approach between the IE and SE models.

To date, most literature on academic entrepreneurship assumes that the scientific inventors become the entrepreneurs (the IE model). In contrast, both literature and practice largely neglect the alternative involvement of "external entrepreneurs," whether under the SE or FA models. Such external entrepreneurs are distinct from the original scientific inventors, and they commercialize the technology with or without collaboration from scientific inventors (Politis et al. 2012). There is some preliminary empirical evidence (e.g. Lockett et al. 2003; Franklin et al. 2001; Siegel and Phan 2005; Leitch and Harrison 2005; Nicolaou and Birley 2003) suggesting that the involvement of external entrepreneurs might be a very effective but largely underutilized mechanism for the commercialization of university-generated knowledge. One advantage of involving external entrepreneurs is that they are likely to have easier access to risk capital and strategic alliances as a result of their previous industry experience and business networks (Politis et al. 2012).

However, little is known on the extent to which scientists and universities are open to this sort of hybrid solution, which does not quite fit the traditional "Technology Transfer Office" approach adopted by many institutions (since they are often focused either on the IE approach or on out-licensing of IP). While a handful of studies have considered the deployment of external entrepreneurs as an alternative to the IE model *per se* (e.g. Festel et al. 2015; Lundqvist 2014; Franklin et al. 2001), practically no research has explored the perspective of individual academic scientists, or how their needs can be matched to existing approaches associated with external entrepreneurs.

With these considerations in mind, this thesis addresses the following two research questions:

What individual-level characteristics matter when choosing an entrepreneurial model to transfer scientific findings to industry through a new venture? And, based on these insights, what is the best way to link academics with existing entrepreneurial approaches? (RQ1 and RQ2 addressed in Paper 1)

The lack of relevant studies on this topic is particularly noteworthy in the context of the plethora of studies on academic entrepreneurship. Although scientific inventors play a central role in entrepreneurial endeavors, as Clarysse et al. (2011) note, relatively little is known about how individual-level factors shape the motivation of academic scientists to engage in entrepreneurial activities. These authors found that it is particularly individual-level attributes, previous entrepreneurial experiences, and the social environment that drive academics' ambitions to become entrepreneurially engaged.

Just as the individual-level factors of would-be entrepreneurs are crucial in business venturing, so those of other supporting actors also play a vital role. Having reviewed the former, we now turn to the latter.

2.2. General entrepreneurship and external opportunity evaluation

Although individual-level differences have been considered as a fundamental determinant of who decides to embark on the entrepreneurial pathway, the existing literature offers limited insights into how individual-level differences affect the third-party evaluation of a business opportunity (Gruber et al. 2015). Whereas the remarks by Gruber et al. (2015) refer to entrepreneurship in general, other authors have been more explicit about the lack of knowledge of individual-level differences when considering academic entrepreneurship in particular (e.g. Shane 2005b; Shane and Venkataraman 2000; Harper 2008). In this vein, Clarysse et al. (2011) point out that, unlike the academic entrepreneurship literature, the wider entrepreneurship literature has paid some attention to individual-level differences as a critical determinant of the decision to become an entrepreneur. Shane (2005b) argues that individual-level differences exert a considerable influence on who becomes entrepreneur, and defines individual differences as "any type of variation among people, whether in their demographic characteristics, such as age or education, or in their psychological make-up, such as motivations, personalities, core self-evaluation or cognitive processing" (Shane 2005b, p. 61).

Would-be founders, but often also external actors, must reach a conclusion on the worthiness of a business opportunity as the final result of an opportunity evaluation process. Williams and Wood (2015) note that, at various unit levels, literature has largely neglected opportunity evaluation, and summarize this research gap as follows: "Intriguingly, across these different areas of research the notion of how individuals, teams, or organizations *evaluate* the worthiness of opportunities, once identified, discovered, or created, remains fragmented, inconsistently treated, and sometimes omitted altogether" (Williams and Wood 2015, p. 218 [emphasis in original]).

This thesis addresses this research gap, thus exploring a topic that is highly relevant to a broad range of actors (i.e. entrepreneurs, managers, and investors). My third research question is:

How do individuals occupying different professional roles vary in their assessments as to what makes an attractive business opportunity? In particular, how may certain linguistic cues influence external people's evaluation of a business opportunity during the earliest phases? (RQ3 addressed in Paper 2)

2.3. Commercializing emerging technologies: The example of nanobiotechnology

Science-based technologies such as biotechnology find it hard to unfold their economic potential because traditional business models that may have worked well in other industries (e.g. computer hardware, software, or semiconductors) often cannot be borrowed. In the context of research-focused biotechnology ventures, traditional models have revealed fundamental flaws, since they have barely allowed small companies to pursue their primary mission of conducting basic and applied research. In contrast, established companies have enjoyed most capital resources, distribution channels, and IPR protection (Pisano 2006). The case of the biotechnology industry exemplified the need for tailored business approaches that take into account the peculiarities of the specific technology and the present industry structure.

Turning away from a "one size fits all" notion, this thesis aims to develop approaches to facilitate the commercialization of one science-based technology: the nascent area of nanobiotechnology.

2.3.1. Introduction to the research case

In general, the confluence of previously disparate research areas, each containing a variety of different tools and methods, holds considerable potential for innovation (Sharp et al. 2011) and may even give rise to entirely new industry sectors. Maine et al. (2014b, p. 1) define the confluence of technologies as "a new combination of previously distinct technologies, [that] evolves when researchers begin to work at the intersection of two or more technology streams, and when products based on this intersection of technology begin to emerge." For instance, the confluence of the previously distinct research areas of biotechnology and nanotechnology, and the resulting novel combinations of scientific insights and approaches, raise opportunities for innovation and commerce (Maine et al. 2014a). At the intersection of both research areas, the field of "nanobiotechnology" is an example of an emerging technology sector, where the transformation of scientific research advancements into commercial products and application is still lagging (cf. Bosetti and Vereeck 2011; Martin 2015; Maine et al. 2014b).

Nanobiotechnology is a good example of a technology for which an effective transfer mechanism has to be determined, allowing the investigation of my overarching research question to extend into a technology perspective. The following sections provide a brief overview of the scientific origins and evolutionary paths of the two underlying technologies, before turning to approaches to foster technology transfer in the field of nanobiotechnology.

2.3.2. Biotechnology

This thesis adopts a narrow definition of biotechnology, and hence focuses on it in the medical context rather than in other domains such as agriculture ("agbiotech"), industry ("industrial biotech," or the use of cells or components of cells such as enzymes to generate industrially useful products), or bioenergy. Instead, the scope of the examination in limited to biotechnology as the use of technological applications centred on biological systems or living organisms, or their derivatives, to develop medicines. Based on this definition, the term "biotechnology" includes various disciplines ranging from genetics, molecular biology, biochemistry, and embryology to cell biology. As result, biotechnology can be linked to biomaterials, cell therapy, gene therapy, immunotherapy/vaccines, protein therapeutics, and some specialty pharmaceuticals and small-molecule therapeutics (Huggett 2016; 2015).

The discovery of recombinant DNA technology in the 1970s and the subsequent surge of VC did not just spark a whole new industry sector, but also led to a rush in related commercial efforts (as evidenced by the number of patents) and to the advent of entirely new products. More concretely, the impetus for the biotechnology industry was the development of "Humulin," a recombinant insulin and the first recombinant drug to receive market approval by the US Food and Drug Administration (FDA) (Paull et al. 2003). The drug resulted from a cooperation between Genentech and the major pharmaceutical firm Eli Lilly. In 1978 both companies signed an agreement that provided Genentech with R&D funding and royalty income on subsequent product sales, in return for the marketing and manufacturing rights to the recombinant insulin product. The agreement overcame the main obstacles to new ventures entering the pharmaceutical industry: substantial costs of about US$ 1 billion, spread over the 10–12 years that is generally necessary to develop a new drug product (Pisano 2006). Investors accept these high costs and protracted lockup periods in return for a promise of exceptional financial performance (Ford and Nelsen 2014). However, the commercialization of biotechnology in the medical context is also beset by risks, such as low and even declining clinical success rates (Calcoen et al. 2015; Smietana et al. 2016) and increasing patent-related legal uncertainties (Brougher and Linnik 2014; Liddicoat et al. 2015). In short, primarily for new ventures in the biotechnology area, the barriers to market access are already high, and the trend is for them to rise even further—at least, without backing from a major corporation with significant capital resources.

Regarding entrepreneurial processes to manage technology transfer, the Genentech-Eli Lilly agreement was a significant event, as it was the first time that a major pharmaceutical firm had basically outsourced a proprietary R&D program, not (directly[6]) to an academic research institute, but to another for-profit corporation. In the following decades, the agreement has stood out as an example to other R&D-focused life-science ventures of how to collaborate with an established firm, thus providing a blueprint for jumpstarting a new industry sector (Pisano 2006).

One important enabler for the rise of the biotechnology industry—that receives particular attention in this thesis—was the emergence of, and startups' access to, substantial VC, once Genentech had showcased the economic potential of biotechnology (Henderson et al. 1999). The rise of the biotechnology sector has been aligned and fueled by a surge of VC injections, in terms of both the number and volume of investments. Over the last few years, fierce competition among investors for the most promising target firms has led to a significant increase in the VC allocation to early-stage ventures—those ventures that are still in the R&D stage and are yet to generate revenues (Huggett 2016; 2015). As result from this intense competition for early-stage ventures, the private (Huggett 2016; 2015) but—due to margin payments in subsequent financing rounds—also the public (Morrison and Lahteenmaki 2016; 2015) biotechnology sectors have been in a boom phase in terms of economic growth and number of new firms (Yang 2016; 2015).

In summary, since the advent of biotechnology in the 1970s, novel strategies have been developed and adopted by companies to manage the technology transfer process (DiVito 2012). Due to flaws in existing business models taken from other industries (e.g. traditional pharma, software, computers, semiconductors), new approaches were needed for the commercialization of biotechnology research results. These novel approaches aimed at enabling firms to conduct basic scientific research as their core activity, while supporting the commercialization of research discoveries and attracting and satisfying financial investors (Pisano 2006).

The following sections provide a brief introduction into the less-matured field of nanotechnology in general, and its application to biotechnology ("nanobiotechnology") in particular. Based on insights from the evolution of biotechnology, the emphasis is on how to support the commercialization of science-based technologies.

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6 Especially in these early stages, Genentech was deeply rooted in academic research institutions. Its technological/scientific foundations, like its team, emerged from the academic research group led by Stanley Cohen (then a professor at Stanford) and Herbert Boyer (then a professor at the University of California, San Francisco). In their co-authored paper (Cohen et al. (1973)) the scholars published their scientific breakthrough on recombinant DNA (Rothaermel and Thursby 2007; Rothaermel 2001).

2.3.3. Nanotechnology

According to the United States National Nanotechnology Initiative (NNI)[7], nanotechnology can be defined as follows:

> "Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. Nanoscience and nanotechnology are the study and application of extremely small things and can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering." (National Nanotechnology Initiative (NNI) 2016)

More than biotechnology, nanotechnology can be considered as technologically "multidisciplinary" (Bhat 2005; Maine et al. 2014b; Porter and Youtie 2009). Authors have described it as a "collection of tools and approaches" (Mazzola 2003) or a "general purpose technology" (Youtie et al. 2008) with pervasive effects on a broad range of industries (Youtie and Kay 2014; Linton and Walsh 2004).

Considering nanotechnology's high technological potential and versatility (Youtie et al. 2008; Rothaermel and Thursby 2007; Fiedler and Welpe 2010), it is perhaps surprising that it seems to lag behind when it comes to finding a place in concrete industrial products or applications on the market (Maine 2016; Helmus 2006)—particularly, at the confluence with biotechnology (Mazzola 2003; Bosetti and Vereeck 2011). Maine (2014) examines the paradox whereby it is so difficult to commercialize technologies such as nanotechnology (in a wider sense), even though they enable new applications across a wide variety of industry sectors, offer advances to existing products, and pave the way for new products. In her study on entrepreneurial strategies, Maine (2014) identified impediments related to founders' entrepreneurial skills, a lack of awareness of the importance of strategic alliances with incumbent firms, and a diffuse market and product focus. The commercialization of nanotechnology requires novel approaches that differ from those used for other technologies. In this vein, Maine (2014) notes that for the commercialization of nanotechnology it is hardly possible to perform "high fidelity, low cost, quick performing and usefully informative experiments" as postulated by Chesbrough (2010) for innovative business models.

Although there is some work on technology transfer models for nanotechnology in general (e.g. Genet et al. 2012; Nikulainen and Palmberg 2010), there are still major gaps in literature and managerial practice on how to plot a course from the laboratory bench to the market—especially when nanotechnology is used in combination with biotechnology.

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7 The NNI is a U.S. Government research and development (R&D) initiative involving the nanotechnology-related activities of 20 departments and independent agencies and was established in 2000. The NNI today consists of the individual and cooperative nanotechnology-related activities of Federal agencies with a range of research and regulatory roles and responsibilities (www.nano.gov).

2.3.4. Nanobiotechnology as a new field at the confluence between biotechnology and nanotechnology

In the scientific community, the application of nanotechnology insights in biological contexts has attracted huge interest because of the promising ability to specifically modify the properties of probes by controlling their structure and their surface properties at a nanoscale level (West and Halas 2000). In the business world, there has been some commercial engagement with nanobiotechnology following FDA approval of the first nanobiotechnological drug, "Doxil," in 1995 (Maine et al. 2014a; Maine et al. 2014b).

Adopting a process view, there are basically two ways that companies use to enter the nanobiotechnology arena (Maine et al. 2014a): First, "*de alio*" nanobiotechnology firms are established companies that have decided to enter the nanobiotechnology sector, which they do by specifically supplementing their technological capabilities—typically through the purchase of small firms in course of mergers and acquisitions (M&A) activities (for this reason the M&A route deserves particular attention in Paper 4 of this thesis). In contrast, "*de novo*" firms are new ventures that have been specifically created to commercialize the joint outcome from biotechnology and nanotechnology.

Nonetheless, apart from numerous basic scientific studies on the technical potential arising from nanobiotechnology, literature on whether/how it has given rise to a new industry is scant (e.g. Maine et al. 2014a; Maine et al. 2014b).

To this end, this thesis addresses following two research questions:

- *Has nanobiotech already taken hold as a significant addition to the intellectual property portfolio within the established pharmaceutical industry (big pharma), particularly in comparison to the established biotech field? Is big pharma already capitalizing on this new technological area?* (RQ4 and RQ5 addressed in Paper 3)
- *How do established companies respond to the emergence of the nanobiotech industry? What is the role of startups, and what business and R&D strategies should they pursue?* (RQ6 and RQ7 addressed in Paper 4)

Whereas the preceding section was mainly to elucidate the rise of a new technological research field from a business perspective, the following section puts a stronger emphasis on corporate strategies to manage commercialization.

2.3.5. Innovative approaches to turn life science discoveries into business

For the biotechnology industry overall, the high economic and social expectations of this new technology have long been unmet by most companies—a few successful outliers apart (Genentech, Amgen, Celgene, Genzyme, Biogen, Gilead Sciences, etc.). According to Pisano (2006), these difficulties in exploitation have been due to flaws in existing industry structures. Pisano (2006) therefore advocated new approaches[8] to enable new ventures to capitalize on basic scientific research as their core activity—models that have hitherto rarely existed. To overcome the barriers to commercialization, Pisano (2006) suggests, among other things, that companies should improve their focus on specific research/technical topics and enter into fewer, but closer and longer-term collaborations with other enterprises and scientific research institutes. He also recommends a stronger emphasis on "translational research"—that is, closer interlinking between the various phases along the R&D chain up to clinical trials and market introduction. Nonetheless, the current facts indicate that biotechnology has, in the meantime, determined and adopted novel approaches to turn life science discoveries into business. The salient data include the large number of biotechnology products on the market, the strong growth in revenue and profit, and the growing interest of VC investors in providing financing—even to high-risk projects with long lockup periods (Huggett 2016; Morrison and Lahteenmaki 2016; Yang 2016).

Compared to the more mature biotechnology area, the emerging nanobiotechnology field, in contrast, remains largely unexplored. This begs the question of how to design a commercialization strategy—i.e. a tailored business model for nanobiotechnology companies (Maine 2016). Like biotechnology, nanobiotechnology might also be in need of finely calibrated, more nanobiotechnology-specific technology transfer approaches. In this vein, Maine et al. (2012) point out that nanotechnology is based on process innovation, and go on to examine the value creation of firms. They compare 12 ventures that draw on either process-based (nanotechnology) or on product-based (fuel cell) innovation. They find that firms building on process innovation (such as nanotechnology) face greater uncertainty in their value chain positioning, market breadth, and customization compared to more-often-studied product-innovation-based ventures. For these reasons, various authors (e.g. Genet et al. 2012; Maine 2016) have called for different, more nano-specific commercialization approaches that take into account some peculiarities of this new technology and build on insights from the evolution of other science-based industries, such as biotechnology.

Building on the example of nanobiotechnology, these lines of reasoning lead to the following research question:

> *How can new industries achieve commercial breakthroughs, while developing an organizational model through which new entrants could cooperate and compete with both established organizations and academic departments?* (RQ8 addressed in Paper 5)

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[8] More specifically, Pisano (2006, p. 2) calls for changes in the industry "anatomy," which he defines as the system of "direct participants (start-ups, established companies, not-for-profit laboratories, universities, investors, customers); the institutional arrangements that connect these players (markets for capital, intellectual property, and products); and the rules that govern and influence how these institutional arrangements work (regulations, corporate governance, intellectual property rights)."

3. Methods and data sources

Table 4 provides an overview of the research methods and data sources used in the five papers of this thesis. As outlined in Section 2, each individual paper has a different thematic focus with a distinct set of research questions. To address these research questions, the papers draw on qualitative, quantitative, as well as descriptive methodological approaches. This chapter explains why the respective research method was chosen, and what data was used to obtain the results presented in Section 4 below.

Table 4: Methods and data sources across papers

#	Title	Method	Empirical data	Geographic scope	Unit of analysis
1	*To each his own: Matching different entrepreneurial models to the academic scientist's individual needs*	Qualitative case studies	Expert interviews	Zurich	Academic group leaders
2	*Is value in the eye of the beholder? An empirical study of how entrepreneurs, managers, and investors evaluate business opportunities at the earliest stages*	Quantitative	Business idea/plan competition database	Switzerland	New venture projects
3	*Nanobiotech in big pharma: A business perspective*	Descriptive	Patent data retrieved from *Derwent Innovation Index* (http://thomsonreuters.com/) and product revenue data from company annual reports	Global	Big pharma companies
4	*Sourcing innovation through M&A: Lessons from nanobiotechnology*	Descriptive	M&A and financial performance data retrieved from *Thomson Reuters Eikon* (http://thomsonreuters.com/)	Global	Life science companies
5	*Commercializing nanobiotech: Time to take stock*	Descriptive	Financing data from the global life science VC database '*Biotechgate*' (http://www.biotechgate.com). Patent data retrieved from *Derwent Innovation Index* (http://thomsonreuters.com/)	Global	Life science companies

3.1. Paper 1: Interview-based comparative case study

Paper 1 aims to investigate the views of academic scientists on their own entrepreneurial engagement and to match these views with three existing entrepreneurial models—the IE, SE, and FA approaches. So far, none of the three entrepreneurial models has been investigated in a comprehensive and comparative manner, or from the academic scientist's perspective.

3.1.1. Research design

To examine the question of what individual-level characteristics of academic scientists matter for the choice of an appropriate entrepreneurial model, Paper 1 draws on a qualitative case study approach. This approach is particularly appropriate for providing rich contextual insights and in-depth understanding of processes in entrepreneurial venturing (Rasmussen et al. 2014). In general, qualitative case-based methods are the most common methods used to study new-firm creation processes (Rothaermel et al. 2007; Neergaard and Ulhoi 2007) and this research method is, thus, deemed suitable for addressing the research question of Paper 1.

3.1.2. Data collection

To obtain a comprehensive representation of the views of scientists from different technological fields, I selected three departments at the Swiss Federal Institute of Technology Zurich ("ETH") in disciplines that Shane (2004) suggests produce the majority of USOs: 1) Biosystems Science and Engineering; 2) Mechanical and Process Engineering; and 3) Materials Science. Based on a structured list of the professors at ETH on 20 February 2013, obtained from the staff administration office, I contacted all the professors in these three departments via email, to invite them to participate in the interview study. The total number of professors contacted was 59, of whom 16 agreed to participate: a 27% positive response, and a representative sample of the overall population.

To supplement the insights from these interviews, a further 18 interviews with other subject experts (e.g. founders, serial entrepreneurs, TTO representatives) were conducted.

3.1.3. Data analysis

In the data analysis, I ultimately identified following seven primary codes: 1) Technological research focus; 2) Motivation and professional career plans; 3) Financial sources and ownership; 4) Market potential; 5) Entrepreneurial and business expertise; 6) Operational execution and supporting actors; and 7) Organizational structures and board of directors. Following the approach in Nelson (2014), I do not claim that these coding dimensions are exhaustive and/or mutually distinct, but simply that they reflect the aims of the research study: to enhance understanding of the individual-level aspects that impede academic scientists from commercializing their discoveries, and how these impediments can be overcome based on existing entrepreneurial approaches. These primary codes and, thus, the empirical data on the characteristics of co-founders, can be clustered into three general themes related to: 1) the technology; 2) the market and business; and 3) aspects that Wasserman (2012, p. 97) subsumes in the term "soft factors" (e.g. risk tolerance, commitment level, personality, time horizon).

3.2. Paper 2: Regression analysis on archival data

To address the research question of how individuals with different professional roles vary in their evaluation of given business opportunities, we need to better understand the individuals' opportunity templates, which are central. Opportunity templates are mental schemas or knowledge structures that people impose to give meaning to the information available (Dutton and Jackson 1987; Walsh 1995). They are the nexus between two observable variables: 1) information about the venturing project, which is mainly transmitted by linguistic cues (potentially backed up by visual illustrations and numbers) as the independent variables; and 2) the points score that the project receives in a startup competition as the dependent variable. However, the connection remains relatively obscure, and linking these variables enables us to deduce insights on the structure of opportunity templates.

3.2.1. Research framework

Regarding the research framework, Paper 2 draws an analogy with early experiments by Rutherford on atomic structure (Rutherford 1911). These results enabled nuclear physicists to deduce an atomic structure based on how an alpha particle beam scattered when it struck a thin metal foil (e.g. gold). The scientists noticed that many alpha particles simply passed right through the empty space in the atom, while others were deflected. They inferred that the deflection occurred when particles passed near the nucleus.

This has some striking parallels with Paper 2's investigation of how jurors arrive at different evaluation results—or, more precisely, how differences in evaluation results are related to specific cues in the business idea/plan document. In Rutherford's experiments, the atomic structure was the yet-to-be-decrypted link between the beam of alpha particles and their impact point on a detecting screen. In the context of Paper 2, it is each individual's opportunity template that is the "black box," which is targeted with certain cues contained in a business idea/plan document and generates variations in people's opportunity evaluation.

Along these lines of reasoning, the research framework of this study must be designed to discern cues with significant effects on the opportunity evaluation from those of lesser impact. In other words, in the language of atomic science, some informational cues may simply "fly straight through" the opportunity template without significant deviations, and thus have minimal impact on the evaluation score. Summarizing these thoughts, the resulting research framework of Paper 2 is presented in **Figure 2**.

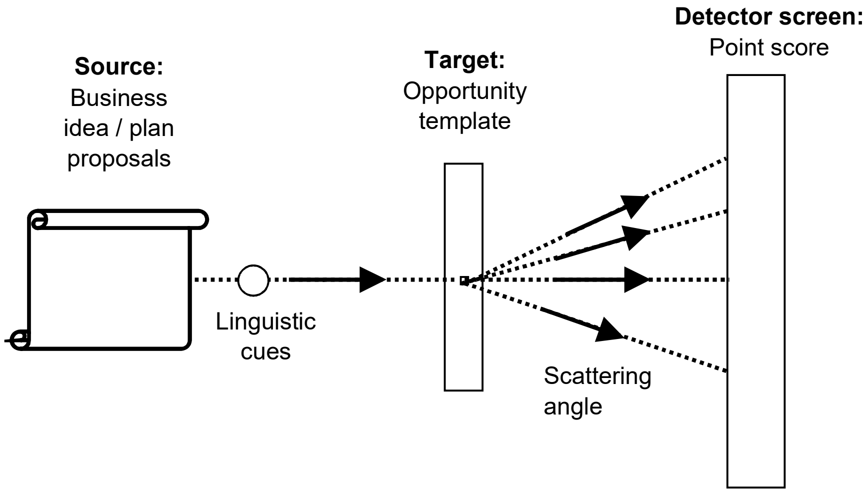

Figure 2: Research framework based on Rutherford's (1911) gold foil experiment.

Figure extracted from Paper 2.

We expect that professional role influences an individual's view of a business opportunity, and thus their business-opportunity template[9]. This, in turn, may lead to heterogeneous preferences and judgments about a given set of opportunities among groups of individuals.

3.2.2. Data source

The study uses archival data from a Swiss-wide startup competition, in which I was involved as part of the administration team in early 2015. As the primary source of data, the database of the startup competition contains business-idea and business-plan documents and metadata at the team and individual levels for the editions of the contest held between 2004 and 2014. Consequently, the data spans a 10-year time period, equivalent to six editions of the biennial competition, for which a total number of 693 business ideas and 379 business plan documents, written in English, were submitted and available for research purposes.

Each edition of the competition comprised *two sequential streams*: a business-idea contest and a business-plan contest. In the business-idea stream, startup teams had to submit a concise (six pages maximum) and compelling document in the form of an executive summary, primarily focusing on customer benefits and potential markets. This format aimed to encourage people to consider entrepreneurship and provide guidance during the earliest exploration. In the business-plan stream, teams submitted a more detailed (20–30-page) analysis of the business opportunity, including sections on financing, opportunities, and risks; the management

[9] Opportunity templates consist of schemas or knowledge structures that people impose to give meaning to information available on a specific item (Dutton and Jackson 1987). The interpretation and processing of the information cues often follows an "automatic" procedure (Dutton 1993; Barreto 2012). So, once an opportunity has been identified and a sufficient set of relevant information on it is available, people devote "limited cognitive effort or expenditure of attentional and analytic resources" (Dutton 1993, p. 341) when imposing their individual opportunity templates (Barreto 2012; Gruber et al. 2015).

team; market and competition analysis; and an implementation plan. Startup teams could enter either or both streams; we investigated the two separately.

Across both streams of the competition, the results draw on a total of 4198 juror evaluations over the examination period 2004–14. Before starting further analyses, we split the organizer's juror category "entrepreneur" into "effective entrepreneurs" (those who had actually co-founded a new firm) and "managers." As result, from the total pool of 4198 juror evaluations, 1413 assessments were attributable to jurors with an entrepreneurial background, 1266 to those with a managerial background, and another 1519 to jurors with an investor background.

Foo et al. (2005) note that the judges of a business-plan competition are gatekeepers of a variety of resources. The juror panel of the examined startup competition comprised executives with a range of industrial and functional roles, including experienced entrepreneurs, business angels, VC investors, bankers, and senior managers of incumbent firms. The ability to convince these gatekeepers of the viability of a business opportunity is not only essential for doing well in the contest, but also acts as an important indicator for whether the would-be entrepreneurs can secure resources including financial capital, business networks (Birley 1985), and advice.

3.2.3. Data analysis

Paper 2 utilizes a regression analysis to investigate the business opportunity evaluation decisions by individuals occupying different professional roles.

Study variables: To analyze the large number of documents submitted to the competition for certain cues in the text body, we utilized the well-established psycholinguistic software tool "Linguistic Inquiry and Word Count" (LIWC) (Tausczik and Pennebaker 2010; Pennebaker et al. 2015). Based on an internal dictionary, LIWC scans text files for the occurrence of words that relate to predefined psychology-relevant categories (e.g. risk or reward cues). It calculates the prevalence of word categories expressed as a percentage, controlling for the length of the text (Riordan and Kreuz 2010; Crilly et al. 2015). Analyzing the words people use, and in what frequency and context, provides information that can be used to gauge their psychological states and processes, and various aspects of their personality (Konnikova 2015; Nadkarni and Chen 2014). Linguistic analysis is increasingly used in research on entrepreneurship (e.g. Wolfe and Shepherd 2015; Moss et al. 2015) as well as general management (e.g. Nadkarni and Chen 2014; Pfarrer et al. 2010; Crilly et al. 2015).

The theorizing and hypotheses development sections of Paper 2 focus on a selection of linguistic cues that literature suggests are centrally important for external evaluators: affiliation, achievements, power, reward, and risk. Based on these five cues, we tested a set of hypotheses, positing that some of these cues from the business-idea and business-plan proposals are relatively more salient to certain types of jurors.

Following the approach used by Gruber et al. (2015), the starting point of the whole analysis was the test for (potential) heterogeneity in opportunity evaluations by calculating pooled ordinary least-squares (OLS) estimations on two different levels: first on the evaluation scores from all types of jurors overall, and second for the three distinct groups of jurors.

3.3. Research topic 3: Analysis of patent data and product revenues

3.3.1. Paper 3: Analysis of patent data and product revenues

As mentioned above, the third research topic encompasses three papers (Papers 3, 4, and 5), each with a different focus and with variations in terms of method and data.

The purpose of Paper 3 is to re-examine whether nanobiotechnology has yet taken root as a significant addition to big pharma's IP portfolio. The aim is to compare nanobiotechnology with the established biotechnology field, and to ask how much big pharma is already capitalizing on this new technological area.

For the analysis in Paper 3, we identified the top 25 pharmaceutical / healthcare companies based on their US$ market capitalization as at 22 September 2015. Next, we systematically retrieved patent information for our sample firms from 'Derwent Innovations Index', the world patent database. We identified a total of 86,664 different patent families. Based on the International Patent Classification (IPC) codes (see http://www.wipo.int/classifications/ipc/en/), we determined the technical subject area of each patent family.

Further details of the research method used are provided in the **Supplementary Information to Paper 3** in **Appendix I**.

3.3.2. Paper 4: Analysis of M&A data, financial performance data, and product revenues

Paper 4 aims to shed light on the role of startups and how established companies respond to industry evolution. Based on these insights, the goal of Paper 4 is to deduce science-to-business strategies that established companies should pursue.

The longitudinal analysis of M&A activities is based on Thomson Reuters Eikon data for the period 2005–2014. In line with Maine et al. (2014a), I focused globally on firms that target human healthcare and that have capabilities in both nanotechnology and biotechnology. By systematically matching the companies from the M&A data retrieve with Derwent Innovations Index, the world patent database, I identified 596 individual M&A transactions where both technological disciplines were present over the examination period.

Initial results were scrutinized and refined through feedback from various nanobiotechnology experts. In total, I obtained feedback from 11 experts, including academic scientists, founders and CEOs of startups, IP experts, and M&A professionals in order to vet the results and obtain more detailed insights into the nascent nanobiotechnology industry.

Further details of the research method used are provided in the **Supplementary Information to Paper 4** in **Appendix I**.

3.3.3. Paper 5: Analysis of venture capital data and patent data

To examine the financing situation of nanobiotechnology SMEs in comparison to traditional/pure biotechnology companies, we collected financing data from Biotechgate (http://www.biotechgate.com), the global life science VC database, and systematically matched them to patent data from the Derwent Innovations Index (Thomson Reuters). Based on the priority application date of the companies' patents, the matching enabled us to draw conclusions on the relationship between the IP portfolio (at the date of the investment) and the investment amount.

As result of this matching, we identified a total of 188 investment rounds (= 56 recipient companies) between 2007 and 2014 where the target company had already filed patents in both nanotechnology and biotechnology strands ("nanobiotech"), and another 1701 financing rounds (= 737 recipient companies) where the target firm had only filed biotechnology patents at the date of financing (irrespective of any patents from other technology areas). To mitigate potential biases arising from different ages of the companies in the biotechnology vs. the nanobiotechnology group, we only included companies/transactions in which the target companies were no older than 15 years. This step also supports our focus on young technology firms in the investment analysis.

Further details of the research method used are provided in the **Supplementary Information to Paper 5** in **Appendix I**.

4. Results

Building upon the previous sections' description of the objectives and methodological approach, the present section describes the main results of the individual papers.

4.1. Paper 1: To each his own: Matching different entrepreneurial models to the academic scientist's individual needs

The empirical results of Paper 1 suggest that there are significant differences in scientists' intrinsic motivation (Lam 2011) to become entrepreneurially engaged. Several interviewees claimed to have good inventions with commercial potential, but admitted that they had only demonstrated proof of concept at the laboratory or prototype scale. Subsequent questions about how they proceeded revealed differences in views and motivations. The different views on engaging in a new venture indicated the need to differentiate scientists according to the three types before determining an appropriate approach. So, as result of the qualitative research interviews, a typology was developed for the interviewees based on their views on engaging in university spin-off projects, and their experience of them (**Table 5**).

Table 5: Statements indicating the necessity to differentiate between different types of scientists based on their attitude towards commercialization

Classification	Characteristics	Exemplary quote
Type 1 scientist	● Gears academic research towards market needs and commercialization. ● Co-founding plans or experiences together with other technological scientists.	"So obviously in *my* specific case, the research is very fundamental; so we are interested in how we really can discover new physics or new mechanics behind materials, but there is always an application in mind. So I absolutely encourage technology transfer where possible. And I think in general [...] there is a lot more potential in this research and in this field in general, than is actually exploited. I think a lot of it is lost in publications that are hard to read, and is lost in this *gap* that exists between what we do in the lab and what you need to have in your hands, the prototype that you can show someone to get a startup company off the ground."
Type 2 scientist	● Very strong focus on academic targets. ● No ambitions to engage in a venturing project.	"I don't make things that are totally without any [economic] potential, and of course we have a research question in mind which might also be important for industry. But we never go that far, we only provide the basics—no more. And to assemble anything with these basics, which is closer to an application, that's the job of others."
Type 3 scientist	● Seeks market orientation and feedback for research projects. ● Openness to a venturing project together with an appropriately skilled business partner.	"[I]t's also very important for me to have this feedback from industry, so that I don't want to push something [a certain scientific project in this professor's research group] which from an academic perspective might be the brilliant solution, but which business people would find useless. So I'm very careful about this."

Table extracted from Paper 1.

The classification of the scientists into one of the idiosyncratic types and the related abstraction was the first step towards matching with entrepreneurial models and determining the characteristics that the academic scientist would expect of a potential co-founding partner.

The first type of scientist explicitly targets their research to market needs and commercialization. These “Type 1 scientists” are academic researchers with concrete plans for co-founding a new venture together with other members of the inventor team, or researchers who have embarked on the venturing process for commercial exploitation via a university spin-off.

Similar to the findings in Vohora et al. (2004) and Rasmussen et al. (2014), while some academic scientists were explicit about their efforts to achieve the commercialization of their research results through a university spin-off, others were indifferent or even reluctant about venturing projects. This difference was evident in the response to the original email requesting an interview. Several scientists declined immediately on the grounds that they were too heavily involved in basic research. However, three out of this group were persuaded to participate and are included in the 16 cases labeled “Type 2 scientists.” These scientists have no personal experience as entrepreneurs, and the groups have not spawned any university spin-offs. This type of scientist is reluctant to gear research towards market needs and technological maturity and is more interested in teaching, scientific publishing, and open science.

Most notably, the interview data revealed a third type of scientist who admitted to needing support from business and who might be open to engagement in a venturing project if an appropriate business founding partner were available. These individuals are labeled “Type 3 scientists,” who are generally open to pursuing entrepreneurship to commercialize their technological discoveries, but do not have the entrepreneurial capabilities or resources needed to bring them to the market. The importance of Type 3 scientists having an effective entrepreneurial approach was substantiated by the fact that this group included the highest number of professors in the sample.

The data suggest that the chosen entrepreneurial model depends on the extent to which the scientist wants to be involved in the venturing project. Generally, it is possible to match the three types of scientists to the three types of entrepreneurial models depicted in **Figure 3**. While the IE approach is the most common in literature and in practice, the results of Paper 1 indicate that significant commercial potential could be exploited through the deployment of external entrepreneurs. In particular, the FA model seems to have been overlooked: several interviewees said they could imagine engaging in business venturing if they were supported by an entrepreneur co-founder.

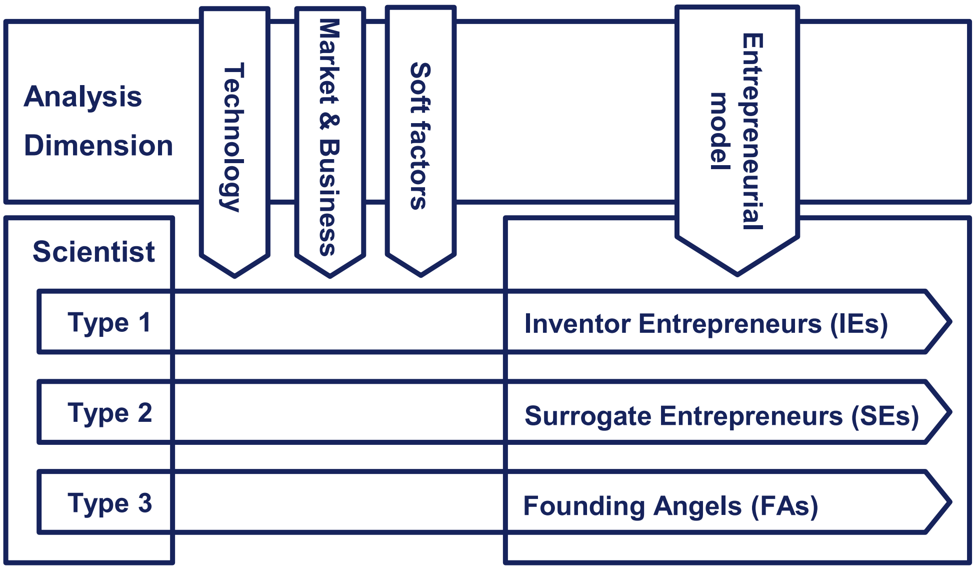

Figure 3: Analysis framework and matching between type of scientist and entrepreneurial approach

Figure extracted from Paper 1.

4.2. Paper 2: Is value in the eye of the beholder? An empirical study of how entrepreneurs, managers, and investors evaluate business opportunities at the earliest stages

In extension to the findings of Paper 1, which indicate the need for a range of technological originators for supporting actors, Paper 2 examines how external evaluators vary in their assessments of business opportunities in two very early phases by conducting a comparative analysis of three stakeholder groups ("gatekeepers of resources") that are crucial to new ventures: entrepreneurs, managers, and investors. Paper 2 investigates the evaluations of a comprehensive group of jurors in a major Swiss startup competition at two different stages: the nascent business-idea stage (submitted document length of about 5–6 pages), and the more mature business-plan stage (20–30 pages). This setting enables deep insights into the relationships between opportunity stage and opportunity templates.

Relying on data on 1072 business opportunities submitted between 2004 and 2014, we connect the linguistic descriptions (i.e., linguistic cues) in these documents with ratings by three types of jurors (i.e., entrepreneurs, managers, and investors).

Considering the set of eight hypotheses posited in Paper 2, **Table 6** presents the summary of the results from the OLS as well as the ANOVA analysis.

For business ideas, neither the comparisons of any two types of jurors, nor all three, show significant differences (Hypothesis 1a, 1b). In contrast, for business plans, ANOVA reveals significant differences when considering all three types of jurors, and when comparing investors with either of the other two types in isolation. In particular, when considering business plans with all three types of jurors, ANOVA yielded an F-statistic of 6.958, which was significantly different from zero ($p = .001$). The results provide partial support for Hypothesis 1a (general heterogeneity in opportunity evaluations). Furthermore, the fact that the differences between the three types of jurors are significant for business plans but not business ideas provides support for Hypothesis 1b (differences in opportunity evaluation depending on stage of maturity).

Table 6: Results summary.

Nr.	Description	Business Idea	Business Plan
H1a	Individuals with diverse professional roles differ in the evaluation of given business opportunities.	Not supported	Supported
H1b	Individuals with diverse professional roles evaluate business opportunities differently depending on the opportunities' stage.	Supported	
H1c	Individuals with managerial and entrepreneurial roles evaluate a given business opportunity in a more similar way than those with investment roles.	Not supported	Supported
H2	The relationship between the number of power cues in a proposal and its evaluation is more positive for entrepreneurs than for managers or investors.	Supported	Supported
H3	The relationship between the number of risk cues in a proposal and its rating is more negative for managers than for entrepreneurs and investors.	Not supported	Not supported
H4a	The relationship between the number of affiliation cues in a proposal and its rating is more positive for investors than for entrepreneurs and managers.	Not supported	Not supported
H4b	The relationship between the number of achievement cues in a business idea/plan proposal and its rating is more positive for investors than for entrepreneurs and managers.	Not supported	Not supported
H4c	The relationship between the number of rewards cues in a proposal and its rating is more positive for investors than for entrepreneurs and managers.	Not supported	Not supported

Table extracted from Paper 2.

In summary, for both business ideas and business plans, most of the study variables did not have a significant impact on the score results for the three distinct types of jurors. Most notably, and contrary to our expectations, reward cues in business-idea proposals are significantly negatively (respectively adverse) related with the judgment of investors (B = -5.110; p = .002). In other words, the results suggest that investors give adverse ratings to business ideas containing plentiful statements related to rewards. For more mature proposals, at the business-plan stage, we found a consistent tendency for investors to reject reward cues—however, the effect is no longer significant (B = -3.106; p = .351).

4.3. Research topic 3: Emerging Technologies

4.3.1. Paper 3: Nanobiotech in big pharma: A business perspective

When analyzing the technological classification of big pharma's patent portfolio from 1994 to 2013, the proportion of biotechnology-related patents compared to the total number of patents ranged from approximately 20% to 30% (**Figure 4**).

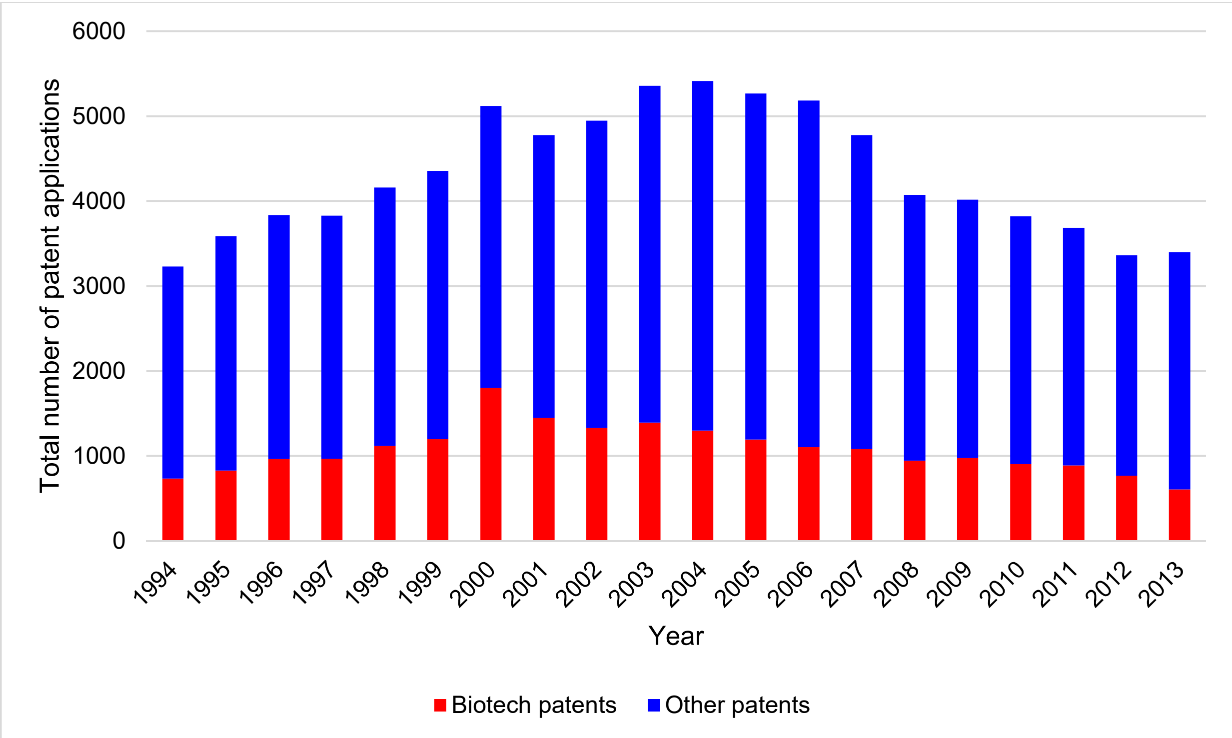

Figure 4: Patent applications of 25 major pharmaceutical companies per year

Source: Derwent Innovations Index. *Figure extracted from Paper 3.*

In contrast, only 0.3% of all patents applied for since 1994 were classified as nanotech. Thus, nanotechnology-related patents represented a very small proportion of the patents in big pharma's portfolio—even when taking into account that nanotechnology is considered an enabling or general-purpose technology, where one discovery is often applicable to a broad range of uses.

The number of patents filed by a company is a poor proxy for the technical and economic value of the underlying IP. Nevertheless, the relatively small number of nanotechnology-related patents in big pharma's patent portfolio can be considered as an indicator that nanobiotechnology is still of only minor commercial importance in the medical therapeutics area. As pharma companies do not systematically disclose revenues for individual nanobiotech-based products, we additionally analyzed the individual revenues of nanobiotech-based drugs that the 25 pharma companies reported as top sellers, as a proxy for the commercial importance of nanobiotech-based drugs for big pharma. For the examined sample of 25 big pharma companies, we identified 14 nanobiotech-based drugs for which the companies reported individual product revenues; in 2015, only four of these achieved annual revenues ≥US$1bn. Most other nanodrugs were way behind these blockbusters, and specific revenue data had not even been separately disclosed for them. In comparison, AbbVie's (North Chicago, IL, USA) biopharmaceutical drug Humira (adalimumab), which topped the rankings of biopharmaceutical drugs by revenue in 2015 (Morrison and Lahteenmaki 2016), accounted for annual revenues of about US$14.0bn, or 61 per cent of AbbVie's total net revenues in 2015. These examples suggest that nanotech-based drugs are still a niche market for big pharma from an economic perspective.

4.3.2. Paper 4: Sourcing innovation through M&A: Lessons from nanobiotechnology

Overall, the macro-perspective on M&A activities reveals that there have been many deals involving significant sums, indicating a coalescence of the nanotechnology and biotechnology worlds. The most noticeable event in the development of total purchase amounts is the drop around 2012—probably the delayed effect from the financial market turmoil in the preceding years. Over time, however, there has been no trend for total amounts to increase, and the results contradict the perception that there is a rush towards nanobiotechnology (**Figure 5**).

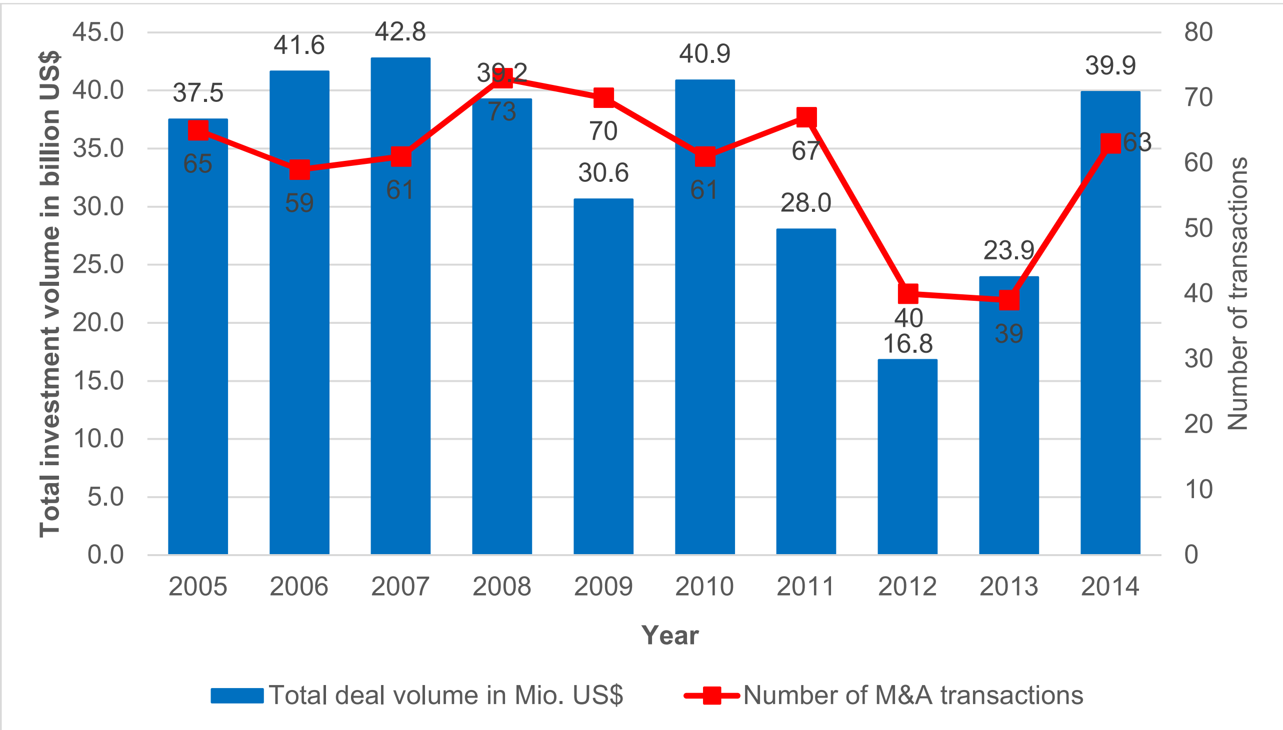

Figure 5: Total number and volume of M&A transactions per year

Source: Thomson Reuters Eikon data retrieve. *Figure extracted from Paper 4.*

The high level of M&A investment volume during the past decade illustrates that established companies spent considerable amounts of money to fuel their product portfolio and R&D pipeline. However, it remains unclear what fraction of each individual purchase price is attributable to the nanobiotechnology sector. Particularly for larger deals in the pharmaceutical area, the acquirers' motivation for the payments is more likely to be found in the traditional pharmaceutical business based on small-molecule chemical compounds, with nanobiotechnology playing only a subordinate role. Considering the contribution of nanobiotechnology products to the total revenue of some pharmaceutical groups, the results indicate that nanobiotechnology is still at an early stage, and represents only a relatively small part of the total healthcare business.

Taken together, the analysis of patent data, product revenues, as well as M&A data in Papers 4 and 5 put the economic significance of nanobiotechnology into perspective, and the results indicate that the new technology still plays only a minor role—at least from a commercial perspective. While Papers 4 and 5 include selective suggestions for fostering the commercialization of nanobiotechnology, the following section focuses on the development of an integrative approach.

4.3.3. Paper 5: Commercializing nanobiotech: Time to take stock

The data analysis shows that, starting in 2009, investors have gradually discovered nanobiotechnology as an attractive investment target. Globally, the *total annual investment amounts* more than tripled from US$189m in 2009 to US$625m in 2013 (**Figure 6**). Over this four-year period, this corresponds to a compounded annual growth rate (CAGR) of ~35%. However, that was just the beginning: In 2014, 41 financing *rounds* were assigned to nanobiotechnology firms, the highest number in the examined eight-year period. Those 41 rounds brought in a total amount of more than US$1.3bn—a leap of 111% over the 2013 record. In line with this surge in the total deal volume, the average deal amount increased from US$7.9m in 2009 to over US$18.4m in 2013 before rocketing to US$32.1m in 2014.

The rising number and volume of capital investments into nanobiotechnology implies increasing interest on the part of corporate VC arms and other investors, and suggests that its commercialization is about to pick up momentum—about 15 years after the launch of the first big nanotechnology research initiatives in the United States (Paull et al. 2003). It is striking that the developments of the investments into nanobiotechnology companies mirror the investments *into (pure) biotechnology* firms—although nanobiotechnology received only about one-tenth of the overall investments allocated to traditional biotechnology (**Figure 7**).

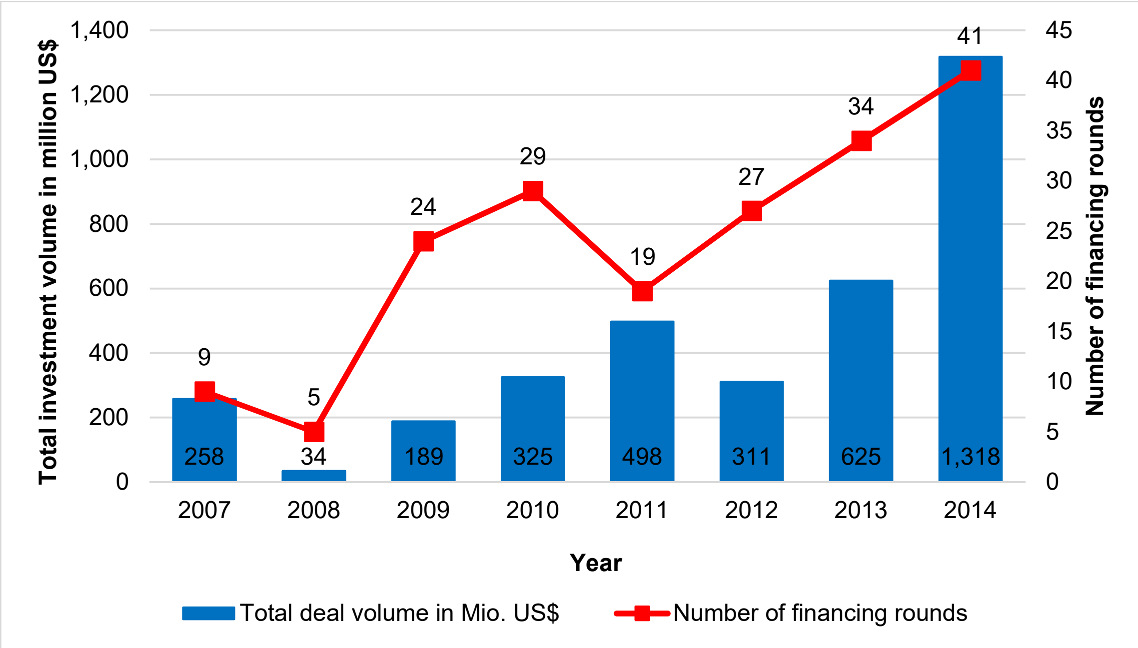

Figure 6: Total number and volume of financing rounds per year for nanobiotechnology companies

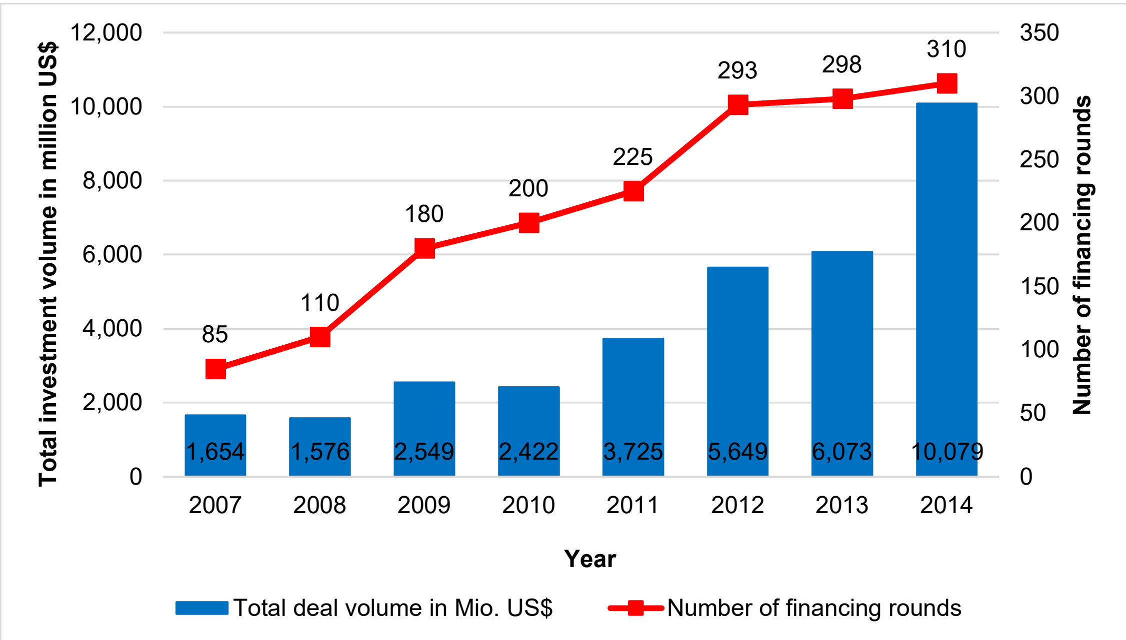

Figure 7: Total number and volume of financing rounds per year for biotechnology companies

Note to Figures 6 and 7: For the purpose of this analysis, **nanobiotechnology companies** are those companies that possess both nanotechnology and biotechnology patents, irrespective of any patents from other/third technology areas. **Biotechnology companies** are firms that possess biotechnology patents but no nanotechnology patents, irrespective of patents from other/third technology areas.

Source: Biotechgate data retrieve. *Figures 6 and 7 extracted from Paper 5.*

5. Implications

The overarching objective of this thesis is to ask, *How can companies make the commercialization of basic academic research results more effective?* Across the individual papers, this thesis sheds light on the drivers and impediments of technology transfer within and between different stages along the process of innovation (see Section 1.5). This section summarizes the key theoretical and practical contributions arising from the individual research papers, while the following one synthesizes some key findings across the papers.

Papers 1 and 2 contribute to entrepreneurship literature and practice alike and put a primary focus on the individuals relevant for commercialization. The more practitioner-oriented Papers 3, 4, and 5 mainly focus on managerial implications for overcoming the technical and environmental obstacles that can prevent emerging technologies from achieving a commercial breakthrough.

5.1. Overview of the knowledge gaps addressed

Figure 8 shows an overview of the topical areas addressed in this thesis, indicating the main concepts and relationships that are relevant for this research. These concepts include:

(a) Literature on the intrinsic motivation and entrepreneurial capabilities of scientists, e.g. Lam (2011), Rasmussen et al. (2014), Hayter (2015)

(b) Analyses of the deployment of certain entrepreneurial approaches, e.g. Franklin et al. (2001), Festel et al. (2015), Lundqvist (2014)

(c) Existing analyses on heterogeneous views, e.g. Gruber et al. (2015), Busenitz and Barney (1997), Williams and Wood (2015)

(d) Industry-specific analyses on the role of incumbents and their interrelation with new ventures, e.g. Rothaermel (2001), Rothaermel and Thursby (2007), Henkel et al. (2015), Genet et al. (2012)

(e) Industry-specific literature on integrative approaches aimed at forging closer connections between basic sciences and businesses of different sizes, e.g. Pisano (2006), Lo and Pisano (2016), Pisano (2010)

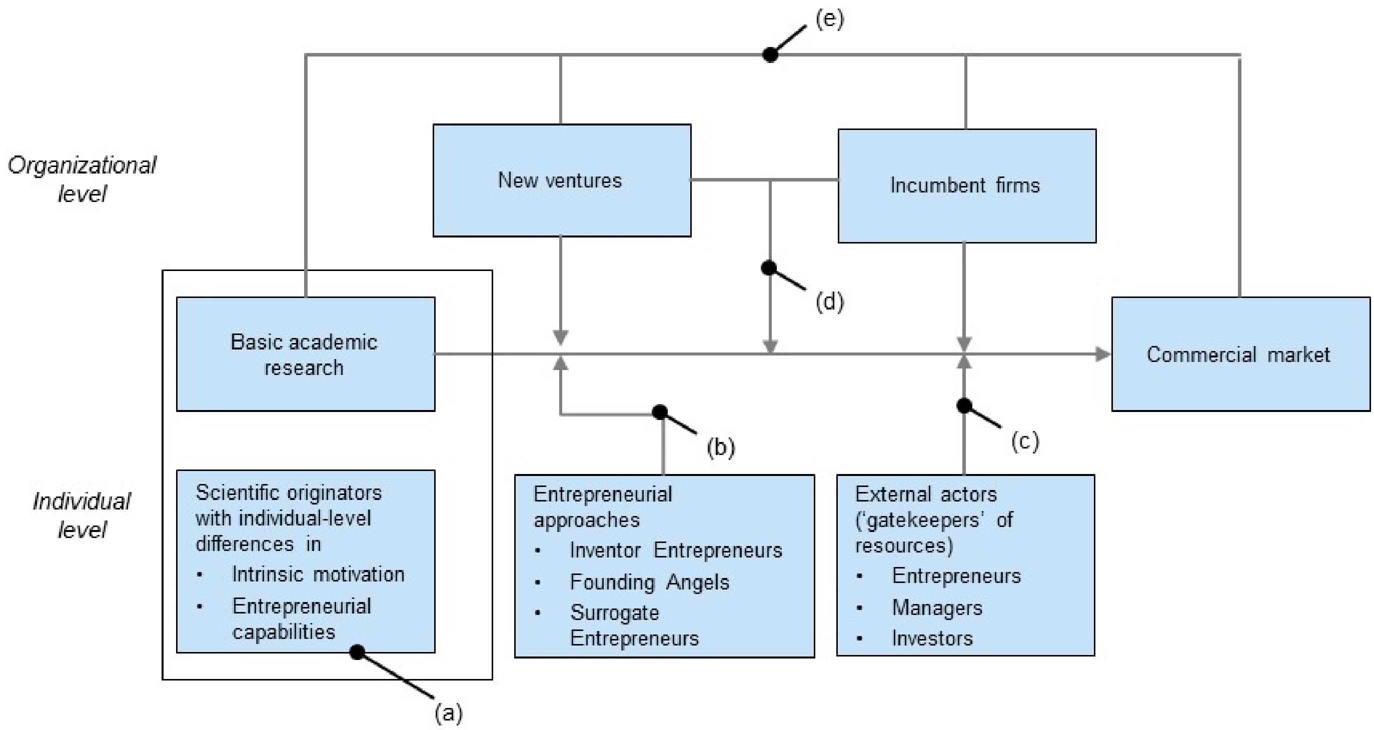

Figure 8: Main concepts and relationships underlying this doctoral thesis

Building on the concepts and relationships in **Figure 8**, **Figure 9** depicts the research gaps addressed in this thesis. Based on a better understanding of the individual-level factors of academic scientists (RQ1), Paper 1 aims to determine a matching logic to existing entrepreneurial models (RQ2). As such, Paper 1 connects two subjects (academic scientists and entrepreneurial approaches) that have not been investigated in a comprehensive and comparative manner, and adopts the academic scientist's perspective.

Paper 2 expands the understanding of the extent to which individuals' opportunity evaluations vary among people occupying different professional roles, and the relationship of these variations to particular attributes of an opportunity (RQ3). To this end, literature provides few insights into dynamic changes in opportunity templates between the stages of new-venture evolution: the nascent business-idea stage, and the more mature business-plan stage.

Whereas Papers 1 and 2 focus on individual-level factors, the practitioner-oriented Papers 3 to 5 focus on the organizational level. The investigation builds on studies suggesting that there is a need for more technology-specific technology transfer approaches (e.g. Pisano 2006; Pisano 1994; Genet et al. 2012). Based on insights from other industries and focusing on one exemplary technology (the nascent field of nanobiotechnology), the research questions in Papers 3 to 5 cover research gaps on incumbent firms (RQ3&4); new ventures and incumbent firms together; and their interrelation (RQ6&7), and on the specification of an integrative business ecosystem (RQ8).

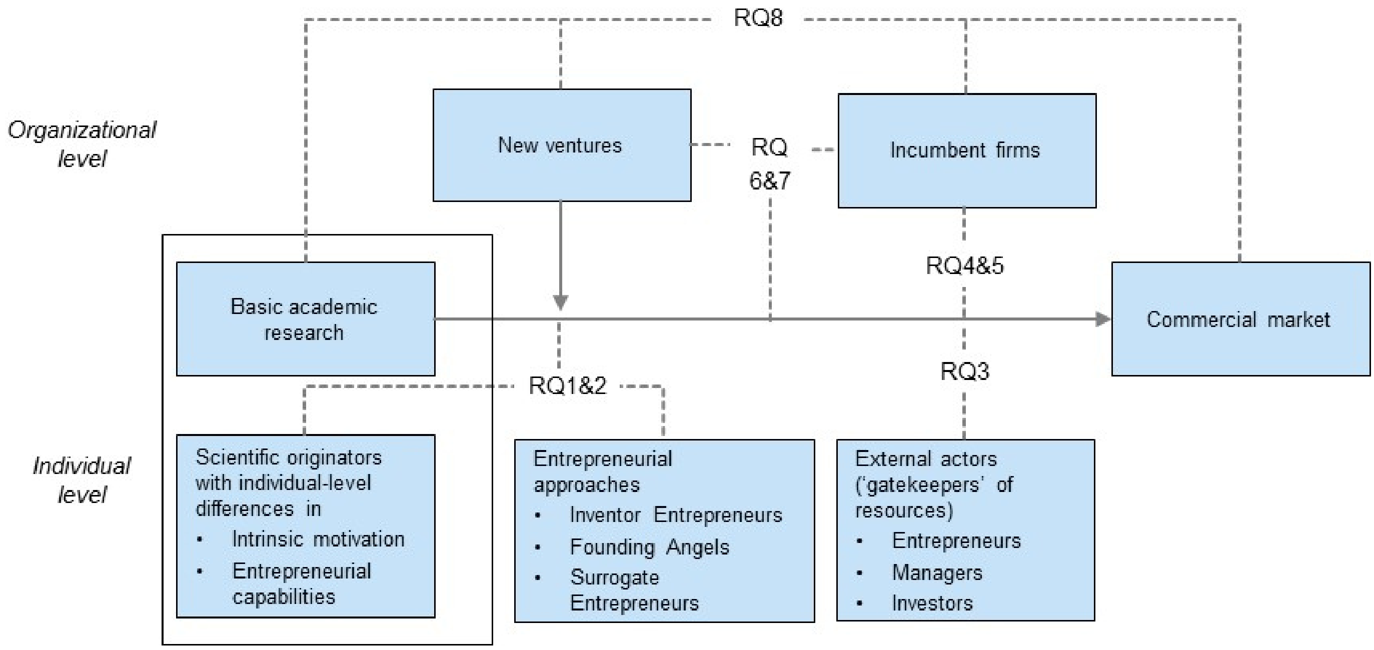

Figure 9: Overview of research contributions of this dissertation, indicating main constructs and relationships

5.2. Contributions to literature

5.2.1. Implications for literature derived from Paper 1

The investigation of entrepreneurial models based on the needs of academic scientists contributes to the literature in two ways. First, the route to commercializing university-generated knowledge through the involvement of external entrepreneurs in a venturing project is considered a promising alternative to the predominant IE model, but has been rather neglected (Politis et al. 2012). Models such as the FA approach have been examined in isolation (e.g. Festel and De Cleyn 2013a; b), and the SE approach has been compared (e.g. Franklin et al. 2001; Kassicieh 2011; Radosevich 1995) to the traditional IE approach, but not in a comprehensive way that encompasses all three entrepreneurial models. Second, the previous literature focuses on the external entrepreneur's perspective (e.g. Festel and De Cleyn 2013b; Kassicieh 2011) or on technology transfer offices (e.g. Festel and De Cleyn 2013a; Franklin et al. 2001), but does not connect the views and needs of scientists with existing entrepreneurial models.

The analytical linking of scientists' perspectives to the three entrepreneurial models, as proposed in Paper 1, reveals that they can be matched based on the scientist's view of a venturing project. For scientists with little interest in commercial activities, the SE model might be the most appropriate approach. At the other end of the continuum is the IE approach, which would seem suitable for those scientists who want to bring their discoveries to market on their own. However, the breadth of the spectrum between these two extremes suggests the need for an intermediate approach. The importance of such an approach is substantiated by the fact that most interviewees ascribed their venturing inactivity to a lack of entrepreneurial support. The FA model, which pairs the scientific inventor with an entrepreneurial co-founder, might be a potential solution. This result is in line with Lockett et al. (2003), Franklin et al. (2001), and Lundqvist (2014), who conclude that an approach that combines inventors and entrepreneurs is likely to be more effective, since both parties contribute particular strengths—whether technological or business and venturing. This paper suggests that external entrepreneurs could add value, and extends the theory by providing empirical evidence. For academic scientists, the FA approach (i.e., collaboration with an external entrepreneur) is one way to gain access to complementary resources such as other technologies required for commercialization, brand, organizational knowledge and, especially, manufacturing capacities (Teece 1986). In this context, the present study adds to the literature on how academic originators of IP can benefit from their research discoveries (e.g. Teece 1986; Agarwal and Shah 2014; Dedrick and Kraemer 2015; Jacobides et al. 2006).

5.2.2. Implications for literature derived from Paper 2

By comparing certain attributes from a total of 1072 business opportunities with their evaluation by a pool of 114 entrepreneurs, 118 managers, and 100 investors, Paper 2 extends the work of Gruber et al. (2015) on how individuals with different professional roles diverge in their preference for particular opportunity attributes. Paper 2 is the first study that has jointly analyzed and compared the preferences of the three key stakeholder groups (entrepreneurs, managers, and investors) based on actual business-opportunity proposals.

To uncover preferences for certain text cues, we employed a novel psycholinguistic approach (Pennebaker et al. 2015) that has increasingly been used in behavioral sciences (e.g. Riordan and Kreuz 2010; Holtzman et al. 2010; Tull and Roemer 2007) as well as general management research (e.g. Nadkarni and Chen 2014; Crilly et al. 2015; Gamache et al. 2015; Pfarrer et al. 2010). Most recently, the linguistic research approach is gradually finding its way into entrepreneurship research (e.g. Wolfe and Shepherd 2015; Moss et al. 2015). The chosen approach is also a response to scholars' calls for deploying more innovative techniques in analyzing large datasets (e.g. Feldman et al. 2015).

Three aspects make the results of the study especially unique. First, Paper 2 is based on actual business opportunities—as opposed to experimental settings, which are often based on a limited number of simplified and fictional cases. Second, the comparative analysis includes three essential target audiences, instead of focusing only on the views of one group with a particular professional role (for example, comparing the evaluation behavior of different (sub-)types of financial investors; e.g. Knockaert et al. (2010), Mason and Stark (2004), and Pontikes (2012)). Third, the study provides insights into how jurors' preferences for certain attributes vary between two stages: the business-idea phase and the later business-plan phase.

The results reveal that as long as there is only rough initial information available (in the form of a business-idea proposal), people's professional role has almost no significant effect on their evaluation. However, once more detailed business-plan proposals are available, the situation changes, and the individual's professional role *does* affect their judgment (**Table 6**). This result underpins the frequently expressed request for a differentiated approach when conducting research on opportunity beliefs, since all opportunities are not equally appealing to all people (Dimov 2010; Wood et al. 2014).

In many cases, the study variables showed no significant effects on the evaluation score. This result further underlines the suitability of the atomic-science analogy (**Figure 2**): just as a large proportion of alpha particles passed straight through the metal film, so our results indicate that cues in a number of categories "passed straight through" the opportunity template, without significant deviations in terms of the evaluation score (**Table 6**). In other words—to continue with the atomic structure metaphor—many cues seem to have passed far from the nuclei of the jurors' individual mental schemas, evading their gravitational pull.

At a deeper level, the regression analysis reveals insights into preferences for specific opportunity attributes. The results indicate that, for a given business opportunity, cues related to power are especially appealing to entrepreneurs, and less so to managers or investors. Entrepreneurs' strong preference for power cues applies to both business-idea and business-plan proposals. In contrast, the results on managers and investors did not support our hypothesized predictions. Most surprisingly, the results indicate that investors strongly dislike reward cues, and we found empirical evidence that this aversion is reflected in the scores investors granted to business ideas. The finding appears counterintuitive, as one would expect investors to be primarily interested in financial returns, and thus favor opportunities that promise rewards and contain a correspondingly high number of reward cues. This is in contrast to technological originators, who typically have a strong emotional attachment to their discovery/idea and hence are supposed to have a strong product (or service) focus. In this vein, one might naturally expect investors to criticize the neglect of reward focus.

Nevertheless, the negative relationship between rewards cues and score must be interpreted with due caution regarding imputations of causality. For instance, it could also simply be that, in weak proposals, the authors include extensive elaborations on potential rewards because they lack a compelling product or service to present. In these cases, it is less the plethora of rewards cues that leads to the poor rating, more the technical weaknesses in the product or service, which the venture team is trying to cover up. Still, remarks on (potential) rewards should be deployed carefully in business-plan and, especially, business-idea proposals—a finding that deserves more attention in entrepreneurship research but also practice.

5.3. Implications for practice

5.3.1. Implications for academic scientists and university policymakers

Most university and public initiatives to stimulate technology transfer and support spin-offs assume that commercialization activity is undertaken by the technological inventor themselves. Although the technology transfer officers interviewed agreed that the use of external entrepreneurs, and especially linking inventors and FAs, was a promising mechanism to enhance technology transfer in several situations, they also observed that, so far, this route had not been explored. The neglect of external entrepreneurs in current policies is due to a lack of awareness and understanding about which entrepreneurial approach is appropriate for which situation, rather than general opposition to such approaches.

Universities keen to use external entrepreneurs need to ensure that the relevant actors (i.e. technology transfer officers, scientific inventors) have a basic understanding and awareness of the existence of alternative entrepreneurial models. Paper 1 provides an overview of the existing entrepreneurial support models and their application possibilities. These models can be used as complements or alternatives to the practices that currently dominate technology transfer activities. Paper 1 offers some guidance about which of the staged entrepreneurial support models would be most appropriate in the particular prevailing circumstances, allowing those involved to make informed choices. In line with Rasmussen et al. (2014), academic policymakers should strengthen their competencies to identify and further develop promising venturing opportunities.

The analysis of the empirical data highlights the important role of the university in providing active assistance and influencing prevailing attitudes to entrepreneurial activities. The extant literature shows that the views held by departmental and university level managers on spin-off projects generally, as well as personal engagement alongside an academic university role, are crucially important for the scientist's decision to engage in entrepreneurial activity (e.g. Rasmussen et al. 2014; Jain et al. 2009). This applies especially to the case of non-tenured faculty who want to continue in academia (Wright 2012; Clarysse et al. 2011). In line with this literature, the interview data obtained from the present study support the notion that many scientists are reluctant to engage in spin-off projects if they are seen as disruptive to department or university relationships. Two frequent concerns expressed by interviewees were the time commitment that a spin-off project would require and conflicts arising from additional financial compensation for academic research activity based on university resources. The reluctance to engage in commercialization might be mitigated by a university environment that was more supportive of spin-off activities (cf. Rothaermel et al. 2007; Clarysse et al. 2011). In addition, consideration could be given to rewarding academic scientists' technology transfer efforts and venturing projects through tenure and promotion decisions. The results in Paper 1 strengthen the conclusions in Siegel et al. (2003) that university policies should signal that business venturing is appreciated by the university, and that a considerable part of the workload related to marketing and business operations could be shouldered by an external entrepreneur.

5.3.2. Implications for entrepreneurial founders preparing a business idea/plan proposal

Entrepreneurial founders should be aware that the text cues in their proposals, and the underlying opportunity attribute they relate to, may have heterogeneous effects on audiences and thus lead to varying judgments of the same proposal. Two evaluators with different professional roles may view the same proposal quite differently simply due to effects from the language cues used in the presentation.

Based on this research, the most important yet basic advice to founders is that they should steer clear of speculating about potential rewards, particularly in the earliest, business-idea phase. Even for professional experts, it's hard to make reliable financial projections in the very early phase of a new venture opportunity, and this applies even more to less-experienced, possibly unskilled founders. Instead, in the business-idea phase, the venture team should focus on describing their product or service, its benefits to customers, or the problem that it aims to solve.

The findings of Paper 2 also indicate that founders should spend time learning about the roles and related preferences of those to whom they send their proposals. If approaching one particular target group, or a number of groups with similar preferences, the venture team should customize their business-plan proposal and emphasize those aspects that are particularly attractive for the specific target audience (cf. Mason and Stark 2004; Petty and Gruber 2011). In this vein, instead of creating a single, monolithic plan and then tinkering with it, venture teams could focus on developing discrete modules of text on various themes that can then be edited together in different configurations to suit different audiences.

Furthermore, the results have also implications for founders who personally have less of a product/service focus. For example, venture founders who possess an investment role themselves might be more likely to include more rewards cues when writing a proposal. For these cases, the results suggest that their proposal drafting input should be balanced with contributions or feedback from someone with more product or customer focus. The input of an external professional editor might also help founding teams achieve the "right" balance (in whatever context) in their proposals. For instance, if teams choose to write in a language that is more "popular" with evaluators (i.e. English), but in which they themselves may not be completely fluent, a native speaker could help make language cues as precise as possible, and avoid misunderstandings in sensitive areas such as speculation on potential rewards. Just as founding teams can get too close to their product, so they can get too close to the proposal that describes it.

The findings might also support some wider applications—for example, in a context with an internal perspective, such as organizational members preparing a proposal for a new product or project that will be considered by the (entrepreneurial) founder of their firm and/or some of its managers. If a new project can be considered as a mini-business in its own right (i.e. it will become a discrete profit center within the organization), some of the same observations may apply to it as for startup firms.

5.3.3. Implications for startup competition organizers

The study reveals important insights into individuals' evaluation of a given business opportunity, and raises issues for the design of business-idea and/or business-plan contests. First and foremost, the organizers of a startup competition, but also coaches on entrepreneurship, should discourage (potential) founders from speculating on (financial) rewards, especially in the business-idea phase.

To obtain a deeper understanding of the preferences of each type of juror and investigate the drives behind their allocated scores, we decomposed the total score that each juror awarded to a project and ran additional analyses on the individual question level[10]. The question-level analysis (see detailed results in the **Supplementary Information to Paper 2** in **Appendix I**) reveals that the correlation between the score for a specific question and the total score awarded by the jurors is quite high (for most questions $\rho > .800$). Given the relatively small number of questions in the evaluation form (in this empirical setting, the investors' form in particular), a high correlation between question score and total score was to be expected. Across all types of jurors, this result suggests that jurors form an overall opinion on a certain project first; and based on this opinion, seem to follow a relatively fixed score distribution system, in which the scores each juror awards to single questions increase or decrease in an approximately linear fashion. In other words, some questions are generally rated more poorly, but based on their overall impression, jurors shift their score points up or down throughout all questions (almost) equally—a phenomenon that calls for further research. Nevertheless, a partitioned evaluation design is to be recommended, for three reasons. First, the individual question rating may prompt the jurors to follow a more structured evaluation process and consider a range of predefined criteria—otherwise, some aspects might be neglected. Second, organizers promote their competitions to participants with the prospect of getting feedback on their business idea/plan proposals from experienced industry experts. Third, a differentiated questionnaire plays a pivotal role in the final stage of evaluation, when it comes to determining the winners of the competition. The finding that single question ratings followed the overall impression was derived by analyzing a pool containing a large number of good and weak business-idea and business-plan proposals.

Taken together, individuals with different professional roles vary in their preferences when evaluating business-plan proposals. People's overall impression of a business opportunity seems to be decisive for their judgment, and the assessment of individual attributes (evaluation questions) seems to follow their overall opinion. Due to the heterogeneity in individuals' preferences, particularly when assessing business plans, and the consequential variations in the total score they give a project, the organizers of a competition should take

[10] On the individual-question level, the dataset contains 9912 ratings by entrepreneurs, 8925 ratings by managers, and another 5070 ratings by investors (business idea and business plan together).

this finding into account when assigning jurors to projects. To mitigate unfair rating biases, a (similarly) balanced number of jurors from each professional domain should vet the business opportunities, at least those on the shortlist.

5.3.4. Implications for business managers in the nanobiotechnology domain

The findings of Paper 3 indicate that—contrary to the impression created by publications on technical advancements and some business reports—nanobiotechnology still plays only a minor role in the established pharmaceutical industry, both in terms of patenting and product revenues. Nanobiotechnology research is generally a lengthy, costly, and technically highly uncertain process; until now, academic institutions have mainly driven innovation in this field. As result, most domain experts are in academia and—even over a decade after the emergence of the nanotechnology hype (Paull et al. 2003)—there is still a shortage of skilled and experienced people able to pick up the academic research results, develop them further, and finally commercialize them. Facing the impending loss of patent protection for many blockbuster drugs, big pharma needs to restock its product pipelines with high-potential innovations (Ford and Nelsen 2014). Technically, nanobiotechnology is supposed to be the salvation to fill the gap, but there should be more debate on the technology's economic prospects.

One option for established companies to attain nanobiotechnology capabilities is to acquire them through M&A transactions. To this end, the findings of Paper 4 suggest that there is an ongoing consolidation of firms in the nanobiotechnology industry through M&A activities. As in some other technological areas, M&A is a popular tool to capture supplementary capabilities and complement firms' own R&D. The results indicate that wisdom from other technology fields also applies to nanobiotech: Whereas large established companies put an emphasis on the exploitation of existing technologies, smaller companies push the exploration of new and uncertain ones. In this context, it may even be disadvantageous for large companies to engage in an "R&D race" (Phillips and Zhdanov 2012) with small firms. Instead, incumbents may be better off "outsourcing" R&D to small firms and then—once promising results are available—cherry-pick the best prospects through M&A. For innovative startups, the possibility of being an attractive acquisition target amplifies the potential gains from technological advancements and provides an incentive to reinforce their own R&D efforts (Phillips and Zhdanov 2012).

Moving beyond the descriptive analyses of the industry evolution in Papers 3 and 4, the focus in Paper 5 is on strategies to facilitate the commercialization of science-based industries—based on the example of nanobiotechnology. Academic research institutions have accomplished major advancements in nanobiotechnology research, as evidenced by a proliferation of scientific publications. Yet, the discussion about its economic impact is still based on conjecture. Compared to the early days of biotech, one might argue we are still in the pre-Genentech phase—that is, we lack a clear, accepted, highly visible example (Freeman et al. 2001) of successful commercialization. As Paper 5 reveals, recent developments in VC investments—

typically the enabler of new technology areas and a key indicator of future technological trends—suggest that the commercialization of nanobiotechnology is gaining momentum just now. These developments mirror those that went before in the traditional biotechnology area—albeit on a markedly smaller scale.

Taken together, the crucial groundwork for nanobiotechnology's path of development is laid within universities. When looking at the affiliations of nanotechnology research publications, it becomes apparent (cf. Paull et al. 2003) that most nanobiotechnology domain experts are still working in academia and are not (necessarily) geared towards taking their discoveries to market. Here, universities must educate and motivate young talents to pursue the commercialization of their research results. Universities are central for turning scientific advancements in nanobiotechnology into social and economic value: in the nanobiotechnology domain, universities are the owners of IPR, and host the talents with the deepest scientific insights into the new technology field. A closer connection between academic scientists and the private sector is needed to achieve a more effective translation of basic research into marketable applications. For instance, *industry secondments* of academic researchers to R&D departments of private companies may not only expand academics' horizons to the business/entrepreneurial world, but may also contribute to a smoother transition of the new technology, including the underlying (tacit) knowledge. Furthermore, a stronger emphasis on "*translational research*" (Pisano 2006) by universities would help to push basic research results further towards the applied end of R&D, and would, thus, make it easier for the private sector to take over.

5.4. Further research

Based on the findings in Paper 1, future research ought to scrutinize the effectiveness of the proposed theoretical matching. In-depth, longitudinal research of nascent university spin-offs would be useful to clarify the critical elements in effective collaboration between scientists and entrepreneurs. Longitudinal research could also uncover which other possible contextual and individual-level variables of both scientists and entrepreneurs need to be considered for the matching. Also, comparative research on a set of existing spin-off companies could investigate which combination of scientist type and entrepreneurial model performs best in terms of team viability (cf. Clarysse and Moray 2004; Foo et al. 2006), growth, and revenues. Lundqvist (2014) provides a comparative analysis of the IE and the SE approaches based on 170 ventures incorporated between 1995–2005, and shows that those ventures using the SE approach achieved significantly better growth and revenue compared to those adopting the IE approach. Further studies are needed in order to include the FA approach in the comparison and obtain a more holistic view of the strengths and weaknesses of all three approaches and their alignment to the individual attitudes of the academics.

Furthermore, mixed-methods studies are recommended, combining insights based on qualitative and quantitative data on spin-offs in order to obtain a more thorough understanding of the effectiveness of the matching.

Robustness tests in Paper 2 revealed that, for the examined Swiss-wide startup competition, business idea/plan proposals in English scored higher than those in German. This result is quite remarkable, given that most judges' native tongue is German, and only rarely English. Future research could analyze e.g. how market focus, growth ambitions, and VC market restrictions drive venture teams' decisions on which language to use for their business idea/plan proposals, and how this decision is related to external judgments.

Furthermore, the business idea/plan competition setting in Paper 2 only focuses on the very early stage. It is not clear how (or indeed whether) the projects evolved after the competition. To validate the accuracy of juror evaluations, future research should apply a retrospective view and compare competition ratings with performance indicators of the project in later stages.

6. Conclusion

In summary, this cumulative dissertation provides important contributions on how to manage the commercialization of new scientific knowledge into viable products and applications on the market. To synthesize the findings across the individual papers, the research shows that there is a need for more differentiated technology-transfer approaches that acknowledge the significant heterogeneity within people's attitudes towards pursuing the commercialization of a scientific discovery with economic potential. The thesis uncovers some key differences in the views of scientific originators of business opportunities, but also in the appraisals of other key stakeholders (i.e. third-party entrepreneurs, managers, and investors). The findings strengthen the perception (Gruber et al. 2015) that the value of a business opportunity lies in the eye of the beholder. Based on these insights, this dissertation offers a sound explanation as to how business opportunities may end up being torn between systematically different views on the viability and exploitation of a business opportunity by key stakeholders from different professional occupations. As a result, business opportunities may get stuck at any one stage of the innovation process, or at the transition between stages (see **Section 1.5**).

We need more differentiated approaches, not only in terms of which individuals are relevant for commercialization, but also with regard to the peculiarities of the specific technological area related to the business opportunity. As examined for the case of one specific science-based technology (the nascent field of nanobiotechnology), there is a wide range of factors that necessitate more specific approaches for fostering commercialization.

The current research found *that* there are systematic differences in individuals' views on a given business opportunity as well as *how* these variations are made manifest in their evaluation. Future research may extend the present doctoral research by enhancing our understanding as to *why* peoples' views on the viability of a given business opportunity are different, and the interrelation with peoples' motivation to become entrepreneurially engaged.

7. Overview of the individual papers contained in this doctoral thesis

Table 7 provides an overview on the five papers of this dissertation, including target journals as well as the current status. Each paper is first-authored or single-authored by the author of this doctoral dissertation. Based on Article 14(2) of the *ETH Zurich – Guidelines for Research Integrity* this implies that for each individual paper the author of this thesis made the main contributions on planning, executing, evaluating the research through personal work as well as on crafting the article manuscripts.

The submission status of the papers is as of 20 October 2016.

Table 7: Overview of papers included in this dissertation.

#	Title	Author(s)	Journal	Status
1	*To each his own: Matching different entrepreneurial models to the academic scientist's individual needs*	Würmseher, M.	*Technovation*	In press
2	*Is value in the eye of the beholder? An empirical study of how entrepreneurs, managers, and investors evaluate business opportunities at the earliest stages*	Würmseher, M. Tata, A.	*Journal of Business Venturing*	Under review
3	*Nanobiotech in big pharma: A business perspective*	Würmseher, M. Firmin, L.	*Future Medicine - Nanomedicine*	Under review
4	*Sourcing innovation through M&A: Lessons from nanobiotechnology*	Würmseher, M.	*Journal of Commercial Biotechnology*	Working paper
5	*Commercializing nanobiotech: Time to take stock*	Würmseher, M. Brusoni, S. Frei, P. Valentini, G.	*Nature Biotechnology*	Working paper

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Appendix I – Individual papers

If one does not know to which port one is sailing, no wind is favorable.

Seneca

Paper 1

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To each his own: Matching different entrepreneurial models to the academic scientist's individual needs

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Highlights

- Technology transfer initiatives often build on inventor-entrepreneur approach.
- Heterogeneity in scientists' attitudes to entrepreneurialism call for differentiation.
- Three types of academic scientists can be identified.
- Typology enables matching of scientists to existing entrepreneurial approaches.
- Involving external entrepreneurs seems to be an underutilized approach.

Abstract

This paper presents a comparative case study of academic group leaders, active in three different scientific fields at a leading Swiss technical university. It examines the obstacles that prevent scientists from commercializing their technologies and how they can be reduced. Traditional models of technology transfer assume that scientists prefer either to 'go it alone' and become entrepreneurs (the inventor entrepreneur model) or to let go of their technologies to people interested in their commercialization (the surrogate entrepreneur model). The results of qualitative research suggest that these two models capture the extremes of a continuum populated by a variety of intermediate situations where scientists are unwilling completely to let go of their findings, but also do not want to become full time entrepreneurs. This results in considerable commercial potential that is unexploited. The Founding Angels approach might be a solution to this problem; it is designed for academics in these intermediate situations. The study contributes to the literature on university-industry technology transfer and should be useful for practitioners and scientists interested in maximizing the synergies between academia and industry.

Key words

Technology Transfer; University Spin-off; Surrogate Entrepreneurs; Founding Angels; Academic Entrepreneurship

1. Introduction

Starting in the 1980s, changes to funding policies and new, emerging scientific fields have been challenging the traditional relationship between academia and industry to include the transfer of technology from universities (Louis et al. 1989; O'Shea et al. 2005; Shane 2004). New organizational models and new funding policies have promoted heated discussion between supporters of the norms of open science (based on free publication and wide dissemination of results) and advocates of more direct involvement of universities in the commercialization of technology. Jain et al. (2009) show that academic institutions are geared towards an increasingly active role in the commercialization process, based on the transfer of academic research results from the laboratory to the commercial market, through licensing agreements or spin-offs. University technology transfer has attracted the attention of researchers resulting in a proliferation of studies at different levels of analysis – technology (Sexton and Barrett 2004; Murray 2002), university management (Wright et al. 2008; O'Shea et al. 2005; Grimaldi et al. 2011; Rasmussen and Borch 2010; Lockett and Wright 2005), departmental influence (Rasmussen et al. 2014; Åstebro et al. 2012; Kalar and Antoncic 2015), early-stage finance (Wright et al. 2004; Knockaert et al. 2010; Wright et al. 2006) and university–industry relations (Perkmann et al. 2013; Clarysse et al. 2011b). The literature provides various suggestions for increasing the effectiveness of technology transfer. This article focuses on university spin-off activity rather than licensing or more general cooperation with industry. University spin-offs are defined as new ventures initiated in an academic setting and based on university developed technology (Politis et al. 2012; Rasmussen 2011; De Coster and Butler 2005; Vohora et al. 2004).

The paper looks at the individual-level features that might explain scientists' decisions to commercialize their findings. Clarysse et al. (2011a) find that academic scientists' individual-level attributes and experience are key predictors of entrepreneurial engagement. Similarly, other studies emphasize the importance of demographic factors, such as age, gender, seniority and prior experience (e.g. Perkmann et al. 2013; Beckman et al. 2007). In the same vein, studies point to the significance of individual-level economic and psychological attributes as determinants for academic scientists' entrepreneurial intentions (e.g. Goethner et al. 2012; Prodan and Drnovsek 2010; Huyghe et al. 2016). However, it is surprising that, despite the significance of individual-level characteristics and the attention they have received in the wider entrepreneurship literature, the individual-level differences of academic scientists have been relatively neglected in the academic entrepreneurship literature (Rothaermel et al. 2007; Clarysse et al. 2011a). Building on extant work and own qualitative research on individual-level motives and entrepreneurial capabilities, the present paper looks at a consequential aspect of the scientist's entrepreneurial decision: *how* to link academics with existing entrepreneurial approaches. While being open to venturing projects, scientists might have distinct preferences about the nature, type and strength of their engagement in the entrepreneurial endeavour. While some might be keen to become entrepreneurs, others might prefer to cede the rights to their invention and leave its commercialization to full time entrepreneurs, but there is a need for intermediate solutions (Berggren 2011; Duberley et al. 2007; Stern 2004; Fritsch and Krabel 2012).

This paper examines different entrepreneurial models and how they match the idiosyncratic characteristics of a sample of 16 scientists operating within a homogeneous organizational and institutional context; the results are triangulated by interviews with 18 professional experts. The research question addressed in this study is: What individual-level characteristics matter when choosing an entrepreneurial model to transfer scientific findings to industry through a new venture? And, based on these insights, what is the best way to link academics with existing entrepreneurial approaches? The investigation adopts the perspective of the individual academic scientist and starts by examining his/her views and needs regarding the creation of a new venture to commercialize a discovery. Based on the findings, this paper examines three entrepreneurial models. These are the two most common models of Surrogate Entrepreneur (SE) and Inventor Entrepreneurs (IE) and the more recent Founding Angel (FA) model.

The remainder of the paper is structured as follows. Section 2 summarizes the literature on academic scientists' views on and needs in relation to the commercialization of their research results. It offers an overview of existing entrepreneurial approaches to commercializing academic research discoveries through spin-offs. Section 3 describes the research method and Section 4 presents the empirical findings. Section 5 discusses some implications for the literature and policy makers. Sections 6 and 7 conclude by outlining some limitations of the study, and summarizing the main results.

2. Background

2.1. Individual-level motives and entrepreneurial capabilities

Much attention has been devoted to analyzing how scientists can translate their academic research results into commercial products or services and how universities can facilitate this process. Perkmann et al. (2013) stress the importance of prior experience and social norms such as age, gender, seniority and colleagues with prior commercialization experience. Organizational support is also important for commercialization. While researchers' involvement in the commercialization process tends to be individually driven (Perkmann et al. 2013), Rothaermel et al. (2007) and Clarysse et al. (2011a) note that analysis of individual-level characteristics has been rather neglected in the academic entrepreneurship literature.

Probably the most important individual-level attribute in academic entrepreneurship is the scientist's intrinsic motivation (Lam 2011) to become entrepreneurially engaged. Jain et al. (2009) highlight that for most scientists in academia, engaging in the business world in parallel with their university activities represents a non-trivial social-psychological challenge related to their specific role in each context. Typically, involvement in a new venture requires some adaptation to their role – an important aspect in discussions on academic entrepreneurship (Huyghe et al. 2014; Ding and Choi 2011; Hoang and Gimeno 2010). According Jain et al. (2009), role changes can be manifested by a shift in activities, an additional workload, and conflicting pressures from the university and industry. These authors point out also that academics often are unwilling to completely abandon 'cherished facets' of their academic role identity when engaging in a commercial project. Academic scientists tend to be mindful of the consequences of technology transfer and keen to preserve these cherished aspects – although with some adaptations. Jain et al. (2009) conclude that an entrepreneurial approach is needed that would enable the scientist to develop a focal academic role identity alongside a secondary entrepreneurial persona. Such analysis is important since intermediate forms of engagement, relying, for example, on the expertise of entrepreneurs, might compensate for the individual scientist's lack of expertise or adversarial social norms.

Alongside these aspects related to individual-level motivation (Lam 2011; Hayter 2015) is another important determinant of engagement in commercialization activity: the presence of three pivotal entrepreneurial *capabilities* (Rizzo 2014). Rasmussen et al. (2011; 2014) describe three competencies required to succeed in new venture creation. First, *identification and development of an opportunity*, which are closely linked to opportunity recognition as a prerequisite for new venture creation (Shane 2000). Due to their business knowledge and experience, external entrepreneurs tend to be better than academics at identifying business opportunities and potential markets (Franklin et al. 2001; Lockett et al. 2005). Second, someone to *champion* the venturing process and attract business and managerial expertise (Visintin and Pittino 2014; Gupta et al. 2006; Wright et al. 2004; Clarysse and Moray 2004). Third, the acquisition, combination and organization of the *resources* needed for commercial exploitation of the opportunity. This applies not just to the resources that are directly related to the innovation in question (e.g. technical equipment, human resources, and the financial capital needed to prepare a prototype). Teece (1986) highlights the significance of having access to complementary resources. Complementary resources can be other technologies which the innovation will enhance, or the resources required for further development, manufacturing and distribution of the new product or service. These complementary resources can range from physical capital (e.g. manufacturing machinery, office space, information technology infrastructure) and brand name, to the organizational and tacit knowledge needed to establish the value chain in order to commercially exploit the invention ahead of potential imitators (Teece 1986; Agarwal and Shah 2014).

Establishing these three capabilities is a challenge for almost all entrepreneurial founders, but especially for those embedded in the non-commercial environment of a public university (Rasmussen and Borch 2010) who want to maintain a focal academic role (Jain et al. 2009). Hence, it is surprising that in proposing the IE approach, the academic entrepreneurship literature generally assumes that the inventor of the technology becomes an entrepreneur (O'Shea et al. 2008; Radosevich 1995; Miner et al. 1992; Freeman and Soete 1997; Kenney and Patton 2009). This assumption may be justified by the fact that the IE approach is the most common outcome in practice (Shane 2004, p. 153; Wasserman 2012, p. 122 ff.). However, it is possible that a considerable number of commercial opportunities are lost due to the scientists' reluctance to adapt their roles and/or due to the lack of these three entrepreneurial capabilities.

2.2. Approaches involving external entrepreneurs in the transfer of technology from academia

Politis et al. (2012) highlight that in the literature and in practice there is a lack of emphasis on the role that external entrepreneurs could play in facilitating the transfer of technology from academia. There is some preliminary empirical evidence (Lockett et al. 2003; Franklin et al. 2001; Nicolaou and Birley 2003; Siegel and Phan 2005; Leitch and Harrison 2005) suggesting that the involvement of external entrepreneurs might be a very effective and under-utilized mechanism for the commercialization of university-generated knowledge (Politis et al. 2012; Visintin and Pittino 2014). According to Politis et al. (2012), one advantage of using external entrepreneurs is that they are likely to have easier access to risk capital and strategic alliances as a result of their previous industry experience and business expertise. However, these authors note that evidence of such benefits is and often anecdotal. Also, little is known about how open scientists and universities are to this sort of hybrid solution, which does not quite fit the traditional technology transfer approach adopted by many institutions. Various authors have called for more differentiated technology transfer approaches, which put a greater focus on the scientist's individual-level attributes (Clarysse et al. 2011a; Lam 2011; Shane 2005) and the strategies that enable scientists to better capitalize on their research discoveries (e.g. Hall et al. 2014a; Hall et al. 2014b; Dedrick and Kraemer 2015). The literature proposes two approaches involving external entrepreneurs - the SE and the FA models - as alternatives (or complements) to the IE model (**Figure 1**).

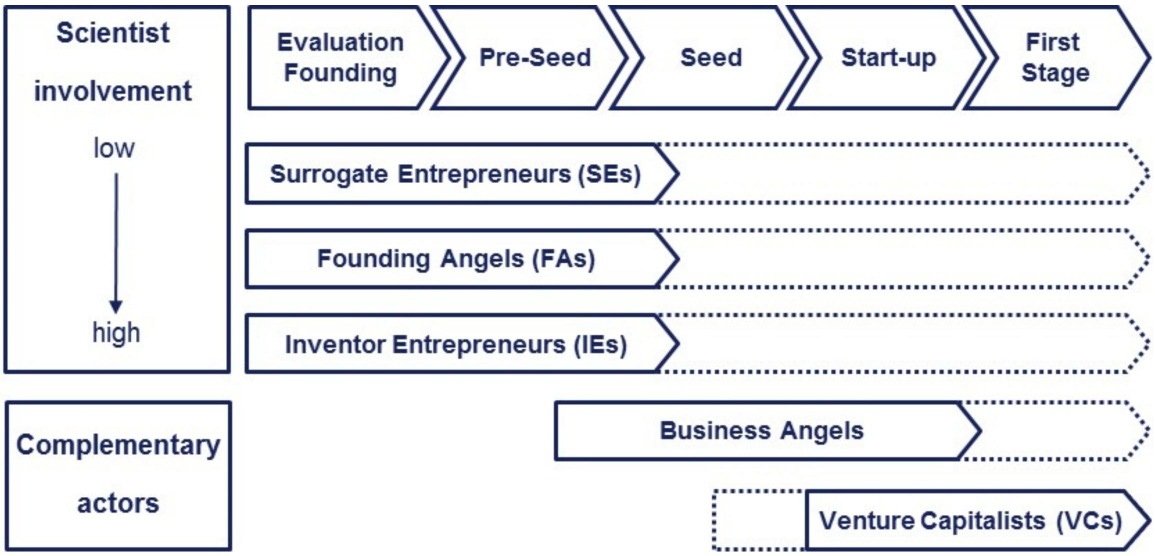

Figure 1: Overview of idiosyncratic starting points of different actors associated with university spin-offs. Figure adapted from Festel (2011).

The alternative of the SE model has also received some attention in practice and in the literature. A SE is someone with business expertise who can bring a university discovery or new technology to the market, mostly without the support of the scientist originator (Kassicieh 2011). Although entrepreneurial involvement is not mandatory for the academic inventor, his/her active advisory support is recommended due to his/her unique level of knowledge as the originator of the technology. This is important particularly in the early stages when technology development is a pivotal business activity (Franklin et al. 2001; Radosevich 1995). Thus, the SE approach describes a model where an entrepreneur from outside the university operates largely independently from the technological originator, but may seek advisory cooperation (Lundqvist 2014; Franklin et al. 2001).

This provides the advantages of the strong technological expertise of the inventor and the strong business background of the SE.

Along similar lines is the more recent and largely unexplored FA model where the scientific inventor plays an integral part in the spin-off project from the outset. Unlike the IE model, the FA is a co-founder with the scientific inventor, providing finance, startup experience, a business network and technical knowledge, and playing an active part, especially in the very early stages of the business (Festel and De Cleyn 2013b; Festel 2011; Festel et al. 2015). In contrast to the SE model, in a FA setting the scientific inventor is actively engaged in the entrepreneurial process. This approach can be adopted at the stage immediately after technological discovery. It represents a middle way that could resolve various problems and might be appropriate for those scientists not keen to commercialize their inventions on their own, but who also are not willing to cede all the rights to their invention to another party. The FA model was proposed as an entrepreneurial approach to manage technology transfer and reduce the financial and operational hurdles at the university spin-off level (Festel 2011). Festel and De Cleyn (2013b), in their study of new venture projects involving FAs, identify ten partly overlapping phases in the FA engagement process. They point to some differences between the FA model and the involvement of actors such as Business Angels and (pre-seed) Venture Capitalists (VCs), which typically are involved in the later stages, after company foundation. Based on a multiple case study and analysis of the perceived drawbacks to the current Business Angel and VC approaches, Festel and De Cleyn (2013b) suggest that the FA model complements these traditional approaches and enables earlier involvement in the development trajectory.

However, the FA model and even the more established SE model have received little attention in literature (**Table 1**) – although these approaches have been used implicitly in some new venture creation. This paper applies these three archetypical ways of framing the academic entrepreneurship discussion (IE, SE and FA) to a data collection strategy to identify those individual-level features that would help scientists to choose the entrepreneurial model that best fits their needs and objectives.

Table 1: Selected studies on external entrepreneurs.

Article	Empirical data	Method	Relevant propositions about the SE or FA approach
Studies covering the Surrogate Entrepreneur (SE) approach			
Radosevich (1995)	Anecdotal experiences from promoting the commercialization of technology from national research laboratories in the US State of New Mexico	Descriptive	SEs are not the inventors, but acquire the rights to commercialize a governmental-sponsored technology. SEs possess accumulated business knowledge, networks and entrepreneurial experience, but may lack specific technological expertise.
Franklin et al. (2001)	Survey of technology transfer/business development officers at 57 UK universities	Quantitative	Those universities that generate the most startups have a more favorable attitude towards the SE approach. A combination of the IE and SE models might be the best approach for universities keen to develop successful technology-transfer based startup companies.
Vohora et al. (2004)	Multiple-case study of 9 university spin-offs in the UK	Qualitative	The SE approach is particularly appropriate if the academic does not want to be committed full time to the venture, or does not possess the skills needed to lead the venture successfully.
Lundqvist (2014)	170 incubated technology ventures 35% of which were based on the SE approach; the results are validated by the use of a single in-depth case study	Mixed method	Swedish surrogate ventures perform significantly better in terms of growth and revenue compared to non-surrogates.
Studies covering the Founding Angel (FA) approach			
Festel and De Cleyn (2013a)	16 interview-based comparative case studies of FA supported ventures in Germany and Switzerland	Qualitative	A process of 10 partly overlapping phases has been identified, providing a framework for FA engagement. FAs engage at an earlier stage than Business Angels or VCs, and FAs are able to complement the roles of the other two investors, which typically start their engagement after the incorporation. FAs add value by (1) providing operational support to the scientific co-founders, (2) bringing in business knowledge and startup experience, (3) providing access to their business networks and (4) offering pre-seed funding.
Festel et al. (2015)	11 interview-based comparative case studies on VC supported startups in Europe and North America	Qualitative	Business Angels as well as SEs and FAs invest their own money which is why there is flexibility regarding exit. In particular, compared to VCs, there is no pressure to exit at a certain amount within a set number of years.

3. Method

3.1. Research design

A qualitative case study research design was chosen since it is particularly appropriate for providing rich contextual insights and in-depth understanding of processes (Rasmussen et al. 2014). A multiple case study approach is generally considered appropriate if the objective is to identify patterns among known categories or dimensions of a given empirical phenomenon. Compared to single case studies, multiple cases are more likely to yield accurate and generalizable results (Yin 2013; Eisenhardt 1989; Eisenhardt and Graebner 2007). In general, qualitative case-based methods are the most common methods used to study new firm creation (Rothaermel et al. 2007; Neergaard and Ulhoi 2007). Multiple case studies are appropriate when there is a need for a deeper understanding and contextual assessment (Miles and Huberman 1994) and were deemed appropriate to address the research question. So far, none of the three entrepreneurial models has been investigated in a comprehensive and comparative manner, and from the academic scientist's perspective. The comparative analysis draws on the existing literature to examine how academic scientists and external entrepreneurs are matched.

3.2. Case selection

Since the focus is on academic scientists likely to generate research results with commercial potential, the choice was made to study selected departments in the Swiss Federal Institute of Technology (ETH) Zurich. ETH Zurich is the largest technical university in Switzerland and has 16 departments related to science, engineering, mathematics, and management. Between 2008 and 2012, the number of spin-offs per year ranged between 20 and 24 (ETH Zürich 2013). The relevance of technology transfer and academic entrepreneurship at ETH Zurich is based on the Institute's strong focus on technological innovation and the research ongoing in its various laboratories, and its influence over the professional paths of its graduates. Alumni surveys (ETH Zürich 2010a; b) reveal that a considerable share of ETH Zurich masters and doctoral graduates take up research-intensive positions in large companies. These surveys reveal also that there are some differences across departments in the proportion of alumni who contemplate setting up their own companies. However, the percentage of alumni who have founded their own ventures is relatively low for all departments and below 10% for some. This gap between the high percentage of alumni taking up research-intensive positions and the significantly lower percentage of graduates starting their own ventures suggests the importance of appropriate entrepreneurial approaches that address the business side of venturing projects.

In their investigation of the role of a university intellectual property system on new venture creation, Fini et al. (2010) distinguish among the university departments in four disciplinary areas: 1) Engineering; 2) Biological and Medical Sciences; 3) Mathematics, Physics, and Statistics; and 4) Social and Human Sciences. In line with this approach, for our investigation, we chose one department for each of the first three disciplines in order to obtain a comprehensive representation of the views of scientists from different technological fields. We excluded Social and Human Sciences since our primary focus is on scientists from technology and science disciplines. In choosing the respective university departments we considered studies identifying departments that had produced particularly large numbers of university spin-offs (e.g. Shane 2004; Fini et al. 2010; ETH Zürich 2016). Specifically, we selected the following three departments as our research setting: 1) Mechanical and Process Engineering; 2) Biosystems Science and Engineering; and 3) Materials Science. Based on a structured list of the professors at ETH Zurich on 20 February 2013, obtained from the staff administration office, we contacted all the professors in these three departments via email, to invite them to participate in our interview study. The total number of professors contacted was 59, 16 of whom agreed to participate (**Table 2**), a 27% positive response, and a representative sample of the overall population.

Table 2: Overview of examined cases.

Case No.	Technological field	Entrepreneurial / industrial experience of the professor	Spin-off(s)			Role of the professor in the spin-off	Professor type[a]
			founded	planned	CEO interviewed		
1	Biosystems Science and Engineering		X		X	Advisor	3
2	Biosystems Science and Engineering	X	X	X	X	Advisor, co-founder, shareholder, BoD member	1
3	Biosystems Science and Engineering			X			3
4	Biosystems Science and Engineering	X					3
5	Mechanical and Process Engineering			X			3
6	Mechanical and Process Engineering	X	X			Co-founder, shareholder, (former) ExB member	1
7	Mechanical and Process Engineering	X	X		X	Advisor, member of BoD	3
8	Mechanical and Process Engineering	X	X			Advisor	3
9	Mechanical and Process Engineering	X		X		Co-founder	1
10	Mechanical and Process Engineering	X	X		X	Co-founder, shareholder, BoD member	1
11	Materials Sciences						2
12	Materials Sciences						2
13	Materials Sciences	X	X			Co-founder, shareholder, (former) ExB member	1
14	Materials Sciences	X	X		X	Advisor, member of BoD	1
15	Materials Sciences			X			3
16	Materials Sciences						2

[a] For the three types of professors, see section 4.
BoD: Board of Directors
ExB: Executive Board

3.3. Data collection

Primary data for each research group were gathered from conversations, visits and interviews. In a first step, the author conducted semi-structured interviews with the 16 professors. With the exception of one interview, which was conducted via a video conference call, the interviews were face to face.

Professor was the chosen unit of analysis; each had several years of experience as an academic scientist, represented a particular scientific discipline, headed a research group and had significant influence on the commercialization of his/her group's research results. From the level of assistant professor upwards, professors have considerable autonomy to set the research direction (Etzkowitz 2003; Casati and Genet 2014).

In order to increase the internal and external validity of our framework and to reduce potential bias resulting from impression management (Eisenhardt and Graebner 2007), we followed the qualitative research approach proposed by Hoppmann et al. (2013) and alternated professor interviews with additional expert interviews. This resulted in four additional data collection rounds (**Table 3**). The first was designed to obtain an indication of potential bias in the views of scientists from the focal university and, to enhance the validity of our interview data, we decided to extend our interviews to another university in the same city – the University of Zurich. The primary focus of the University of Zurich is not technological disciplines. From the University of Zurich, we selected a professor in biochemistry who had co-founded two spin-offs together with partners with different backgrounds, one of which had more than 450 employees. Based on a maximum variation sampling approach in order to capture the views of different people on the phenomenon (Miles and Huberman 1994; Patton 1990), we also selected a computer scientist who had recently co-founded a spin-off in the robotics industry. At the time of the interview, the company had no other employees and the two founders had no prior entrepreneurial experience. In the second round of data collection we asked all 16 professors from ETH Zurich to provide us with the names of alumni of their departments who had co-founded spin-offs from the corresponding research group. The 12 alumni identified were contacted and asked to participate in semi-structured interviews. The nine alumni who agreed are all CEOs in different technology spin-off companies including automotive supplier, robotics, electronic measurement technologies, surface technologies and medical diagnostics. The time since the legal incorporation of these companies was between one and nine years; in some cases operational business activities began a few years after formal incorporation. The number of employees (additional to the founders) ranged from 1 to 19 full-time equivalents.

The third round of data collection consisted of semi-structured interviews with three technology transfer officers responsible for technology spin-offs from five different universities in Switzerland. In the fourth round of data collection, we conducted interviews with two FAs, one Business Angel, and one spin-off coach who is also member of a jury which judges new venture competitions.

Table 3: Overview of data sources.

Stage	Data	No. of interviewees	Main rationale
Interviews (primary data)			
1	Professors ETH Zurich	16	Basis for generating 16 case studies
2	Professor & founder University of Zurich	2	Test for university-specific biases
3	Spin-off founders (ETH Zurich Alumni)	9	Enrich the 16 case studies with additional details; triangulate the statements of the relevant professors
4	University technology transfer officers	3	Insights from experts at the interface between academic science and business
5	FAs, Business Angel, coach	4	Insights from experts with personal entrepreneurial experience from multiple venturing projects
Desk research (secondary data)			
1	ETH Zurich annual reports 2010-2015		Overview of spin-off activities over time and by individual departments, to better understand the relevance of the topic
2	ETH Zurich alumni surveys 2009, 2010		Overview of the professional occupation of graduates to better understand the relevance of the topic
3	Information on each interviewed professor's research group and professional curriculum vitae		Preparation and follow-up of professors' interviews
4	Information on each interviewed founder's spin-off company		Preparation and follow-up of founder interviews

All the interviewees are based in Switzerland. Each interview, 18 with professors and 16 with other academic entrepreneurship experts (**Table 3**), typically lasted between 20 and 40 minutes (see **Tables 8-10** in the appendix for a typical interview guide). The interviews were conducted over the course of approximately one year, from February 2013 to March 2014 by a single interviewer, and were audio recorded (about 18 hours in total) and transcribed. To enable empirical triangulation, we collected secondary data from university annual reports and company information from web pages and press releases, and information on the professors' research groups from web pages.

3.4. Data analysis

The interview transcripts and other relevant material were read and reread as the data collection process progressed and served to refine our research framework (Rasmussen et al. 2014). In line with the recommendations in Eisenhardt (1989), we stopped adding more interviews when the additional insights from the interviews became marginal. Data analysis started with coding of the interview transcripts using the qualitative data analysis software NVivo.

We identified following seven primary codes: 1) Technological research focus; 2) Motivation and professional career plans; 3) Financial sources and ownership; 4) Market potential; 5) Entrepreneurial and business expertise; 6) Operational execution and supporting actors; and 7) Organizational structures and board of directors. Following the approach in Nelson (2014) we do not claim that these coding dimensions are exhaustive and/or mutually distinct, but they reflect the aims of our study: to enhance understanding of the individual-level aspects which impede academic scientists from commercializing their discoveries and how these impediments can be overcome based on existing entrepreneurial approaches. These primary codes and, thus, the empirical data on the characteristics of co-founders, can be clustered into three general themes related to: 1) the technology; 2) the market and business; and 3) aspects that Wasserman (2012, p. 97) subsumes in the term 'soft factors' (e.g. risk tolerance, commitment level, personality, time horizon). These three themes emerged in the majority of the interviews in relation to questions about the barriers to commercializing the technology and what characteristics the interviewee required in a potential entrepreneurial supporter. Our analytical framework, depicted in **Figure 2**, builds on these three themes.

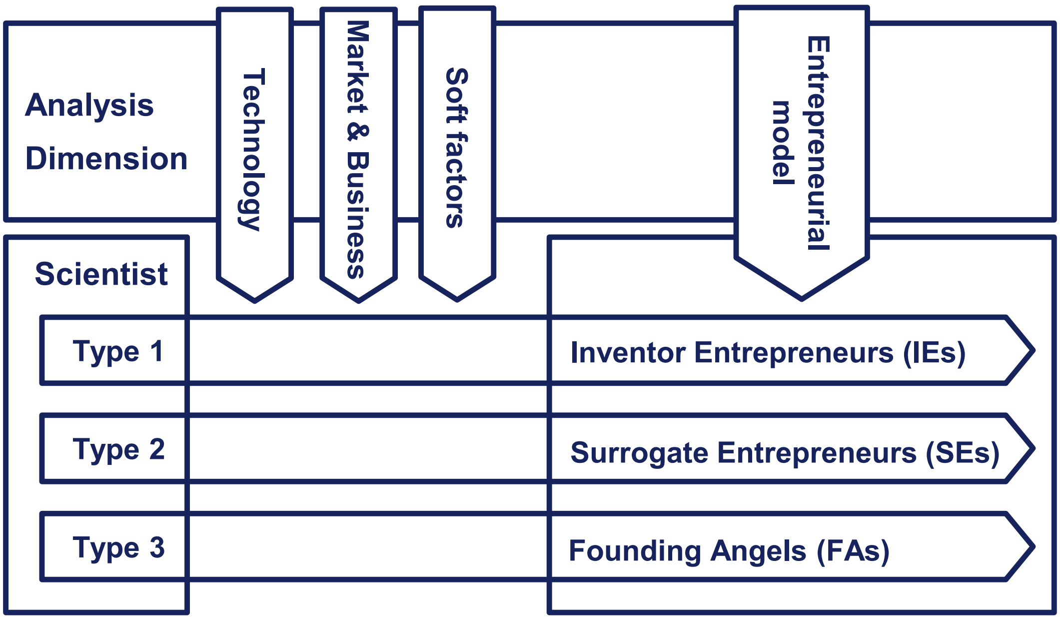

Figure 2: Analysis framework.

Following Yin (2013) and Trochim (1989), we applied pattern matching and compare empirical and predicted patterns in order to identify relationships between the quotes in the interview transcripts and our research framework. This enabled us to draw causal inferences from the chain of evidence and, where the analysis had revealed contradictions in the data, we exploited secondary data to resolve these contradictions through triangulation. In our cross-case analysis, we looked for similar themes across the individual interview transcripts to identify commonalities and differences across cases on one or several parameters of interest (Yin 2013; Miles and Huberman 1994).

4. Results

A typology was developed for the interviewed scientists based on their views on engaging in and experience of university spin-off projects. Classification of the scientists into one of the idiosyncratic types enhanced the comprehensibility of the interviewee's statements by indicating from what perspective it should be interpreted. The need to hire an expert was suggested along with the characteristics the academic scientist would expect of a potential co-founding partner. Based on these insights, how the existing entrepreneurial models could be matched to the academic scientists was analyzed. The following sub-sections discuss the most relevant comments; additional exemplary statements are presented in a series of tables (**Tables 4 to 6**) as additional empirical evidence.

4.1. Identifying types of scientists

Several interviewees claimed to have good inventions with possible commercial potential, but admitted that they had only demonstrated proof of concept at the laboratory or prototype scale. Subsequent questions about how they proceeded revealed differences in views and motivations. The different views on engaging in a new venture indicate the need to differentiate scientists according to the three types, to determine an appropriate approach (**Table 4**).

The first type explicitly targets his/her research to market needs and commercialization. These 'Type 1 scientists' are academic researchers with concrete plans for co-founding a new venture together with other members of the inventor team, or researchers who have embarked on the venturing process for commercial exploitation via a university spin-off.

Similar to the findings in Vohora et al. (2004) and Rasmussen et al. (2014), some academic scientists were explicit about their efforts to achieve commercialization of their research results through a university spin-off, others were indifferent or even reluctant about a venturing project. This difference was evident in the response to the original email requesting an interview. Several scientists declined immediately on the grounds of being too heavily involved in basic research. However, three out of this group were persuaded to participate and are included in the 16 cases labelled 'Type 2 scientists'. These scientists have no personal experience as entrepreneurs, and the groups have not spawned any university spin-offs. This type of scientist is reluctant to gear research towards market needs and technological maturity and is more interested in teaching, scientific publishing and open science.

Table 4: Statements indicating the necessity to differentiate between different types of scientists based on their attitude towards commercialization.

Classification	Characteristics	Exemplary quote
Type 1 scientist	● Gears academic research towards market needs and commercialization. ● Co-founding plans or experiences together with other technological scientists.	"So obviously in *my* specific case, the research is very fundamental; so we are interested in how we really can discover new physics or new mechanics behind materials, but there is always an application in mind. So I absolutely encourage technology transfer where possible. And I think in general [...] there is a lot more potential in this research and in this field in general, than is actually exploited. I think a lot of it is lost in publications that are hard to read, and is lost in this *gap* that exists between what we do in the lab and what you need to have in your hands, the prototype that you can show someone to get a startup company off the ground."
Type 2 scientist	● Very strong focus on academic targets. ● No ambitions to engage in a venturing project.	"I don't make things that are totally without any [economic] potential, and of course we have a research question in mind which might also be important for industry. But we never go that far, we only provide the basics—no more. And to assemble anything with these basics, which is closer to an application, that's the job of others."
Type 3 scientist	● Seeks market orientation and feedback for research projects. ● Openness to a venturing project together with an appropriately skilled business partner.	"[I]t's also very important for me to have this feedback from industry, so that I don't want to push something [a certain scientific project in this professor's research group] which from an academic perspective might be the brilliant solution, but which business people would find useless. So I'm very careful about this."

Most notably, the interview data revealed a third type of scientist who admitted to needing support from business and who might be open to engagement in a venturing project if an appropriate business founding partner were available. These individuals are labelled ‘Type 3 scientists’, who generally are open to pursuing entrepreneurship to commercialize their technological discoveries, but do not have the entrepreneurial capabilities or resources needed to bring them to the market. The importance for Type 3 scientists to have an effective entrepreneurial approach was substantiated by the fact that this type included the highest number of our sample scientists.

4.2. The need for a driving force

Most scientists said they would generally be open to supporting a spin-off project and that there were probably a few research results with commercial potential. However, they were unable to identify anyone able to advance the project – to be the driving force and take on operational management. The perceived lack of suitable personnel also affects the scientists’ views on venturing projects. One professor was evaluating the opportunity related to a first commercialization project and explicitly expressed a desire for more support from an experienced business partner to push the commercialization project ahead:

> *I think sometimes you have to* ‘push’ *the professors a little bit in order to move forward, but it would be good if there was somebody taking us somehow by the hand. […] Or at least if I had the experience of someone who has done it [created a new venture] to help me, then I would come up with more and more [business] ideas. Once I had the experience, if I had idea, then it would work well [to commercialize it].* [Type 3 scientist]

In line with these statements, during the interviews and in the subsequent analysis it was apparent that much commercial potential is lost due to lack of appropriate partners to drive the venturing process.

In summary, the empirical results suggest that commercialization would be more likely when appropriate support from experienced entrepreneurs was available and scientists do not have to cope alone. Unlike barriers (**Table 5**) related to the technology or the market, lack of appropriate personnel could be resolved by involving an entrepreneurial co-founder.

Table 5: Statements indicating the hurdles to academic scientists commercializing their inventions via spin-offs.

Source	Issue	Exemplary quote
Type 2 scientist	Scientists' willingness	"So I am not against startups and other [technology transfer] initiatives in principle […]. But that is nothing for me and it is not in line with my understanding about roles and the responsibilities of a university. Personally, I have almost no legal expertise [...] and I am rather afraid to enter these areas. I think that my personal strengths are in more creative fields. For me, the main tasks of a professor are: first, good teaching of course, but [second], also being creative in research."
Founder	Scientists' willingness	"[...] because [the professors] have no incentive at all [to commercialize a research result]. [The quality of] a professor is measured by the number of papers that he publishes and how much money he raises … - maybe through [governmental funded] projects, maybe through industrial cooperation [...]. The main thing is having the money to fund one's research and to write papers."
Founder	Driving force	"I have already seen 1 or 2 cases where a professor has an interesting thing [research result], but there is nobody available who wants to pursue it [commercially]. [...] I am currently also affected by such a case, where a professor has a promising item for a spin-off, but he does not proceed, as he has not the time and as it is generally not his [core] business. "
Type 1 scientist	Driving force	"I mean the important thing is to have an idea and to have the right people. And I have a lot of ideas… - but if you find the person who is driven to do this, you know the student or the PostDoc [...] who is driven, then do it!"
Type 3 scientist	Technology	"[T]he good ideas and prototypes, that we can develop in the course of a doctoral research project are nevertheless relatively far away from the stage of [technical] maturity, that is needed [...]. For a business plan you must assume that a certain product or device is able to do this and that, 5000 times over the next three years. Through prototypes in the context of doctoral research we have proved that it is possible to do this three times, within two days in the laboratory, but that is quite a difference."
Type 1 scientist	Technology, Market	"You know I've got a lot of publications but the real challenge is seeing your work going into the marketplace. It's easy to write research papers – [but] it's really hard to create a product that people want to buy."
Founder	Market	"I think a patent is written quickly, but whether there is a market for it, that's a complete different question. Oftentimes something comes out of academic research that way: 'OK, that's the solution, now we seek for the [corresponding] problem.' That's the common approach but it has to be evaluated as soon as possible, whether it is really a problem or just a „pretended problem". And as soon as this has been determined, then you can decide: Yes I will found [a spin-off] or not."
Coach	Market	"[T]echnologists often prefer to deliver perfection whereas the market wants functionality and reliability. [...] [T]he biggest challenge you face is that these experts love their technology, they think their technology is great [...] but it's only one very small part of the equation in getting to market: this lack of appreciation of the other required elements is probably the largest hurdle to overcome. They have to understand and recognize the need for a real business to be built around that technology."
Type 1 scientist	Market	"The question is where exactly to apply the new technology? Because let's say a software or a piece of hardware may have multiple uses, and so the question will be: We need some time to figure out where will the startup go to? Should I apply to the biomedical field, or should I apply to some other fields?"

Type 1 scientist	Market	“We are not an industrial company, which operates on the market since 20 years, so we do not actually know the real product opportunities.”
Type 3 scientist	Market	“A physicist or a scientist is able to learn quickly and thinks analytically. However, it initially takes time to get market expertise and experience.”
Type 3 scientist	Business	"Well it sounds like one of the main hurdles is just to know how best to get the attention of investors. In my field you need a fair amount of capital - well it's not like a software type of situation - you need probably a good, at least 2-3 million in the first 2-3 years and to survive even 5 years, you need maybe 10-15 million. So to be able to attract that level of funding you need to have some very good contacts - and a well established business person can do a lot of that [network connecting]."
Type 1 scientist	Soft factors	"I think that even if you have these two skills [regarding technology and business], there is a third skill which has to be equally important and relevant to the rest, which is the belief and the excitement level to make the product work. So you need to believe in what you do."

4.3. Matching the entrepreneurial models to the scientists' needs

The results are presented in line with the three themes described in Section 3.4, starting with the scientists' needs followed by the entrepreneurial model.

The data suggest that the chosen entrepreneurial model depends on the extent to which the scientist wants to be involved in the venturing project (see exemplary quotes in **Table 6**). Generally, it is possible to match the three types of scientists to the three types of entrepreneurial models depicted in **Figure 2**. While the IE approach is the most common in the literature and in practice, our results indicate that significant commercial potential could be exploited through the deployment of external entrepreneurs. In particular, the FA model seems to have been overlooked: several interviewees said they could imagine engaging in business venturing if they were supported by an entrepreneur co-founder.

The aim of this paper is not to investigate the objective validity of scientists' statements regarding the characteristics of potential co-founders. Regardless of whether the scientists' requirements are subjective or objective, they play an important role in the mutual agreement between the scientist and the entrepreneur before and during the course of the business, and may cause an unbridgeable rift between the parties (cf. Clarysse and Moray 2004; Ruef et al. 2003; Foo et al. 2006; Wasserman 2012).

Based on scientists' needs and motivations, three types of academic scientists can be identified and matched to existing entrepreneurial models (**Table 7**).

Table 6: Statements indicating the requirements that scientists require in a potential co-founder.

Source	Topic	Exemplary quote
Type 1 scientist	Technology	"I mean I am an engineer, so I want somebody who appreciates the technology and who understands, you know, *what* is the technological question."
Founder	Market & Business	"I think a senior [entrepreneur] with very deep insights in our industry and with a well-established personal network, that would be a real asset! A *real* asset! But it has to be someone, who has been really [entrepreneurially] active in this field for 30 years - [...] not someone who is just directly coming from McKinsey!”
Type 1 scientist	Market & Business	"I think, I will clearly need somebody with business experience. And that was the real advantage [of company XX] that the CEO was the person who spent 3 years in management consulting [after completing his Ph.D. in the research group of the interviewee]. And he came in understanding how the business world works, which is a lot different to how we work [laughs]. I think somebody with some sort of a background in the area, who understands how to make a presentation to a group of investors and what they are looking for and how to read financial statements and things like that. [...] I mean somebody [with business expertise] that's just invaluable, and we are engineers, we don't know how to do that."
FA and former coach	Business	"It is so easy to make big mistakes if you do not have an in-depth understanding of the technology, so that's a big danger. And there is another caveat that I have experienced several times with other startup companies that hired a business guy, it's often that the business guy comes from a larger organization [...] [who] thinks that with the background in a larger organization he is well suited to manage a startup organization. Very often this fails because being in a startup is much more demanding and you do not have all the backup and all the resources that you have in a large organization. So sometimes the business guys who come from larger organizations, they actually are not able to manage a startup company."
Type 1 scientist	Business	"I mean to have an Angel investor is the best situation […] Venture Capitalists - they are what they are and being an [entrepreneurially] inexperienced like me I'm a little scared... [laughs] You know: They know what's going on and I know that they want to take advantage of me."
Type 3 scientist	Soft factors	"But if the initiative would come from potential Founding Angels, in a simple/informal conversation [and] I do not have to give any commitment [obligation], I do not have to demonstrate anything, but I can just talk about opportunities [then this might be an interesting option to me]."
Technology transfer officer	Soft factors	"So according to my experience a co-founding candidate really needs to have entrepreneurial skills; any experienced consultant or so, that’s not working in most cases - for this conclusion I have already seen a sufficient number of data points where this situation caused tensions or where everyone finally left the project. [...] [Being an entrepreneur means] that he is willing to work through the nights if it is necessary. The second thing is surely, that you must have it in your veins, to solve tensions and conflict situations to the satisfaction of everyone involved."

Table 7: Matching Summary.

	Inventor Entrepreneur (IE)	Surrogate Entrepreneur (SE)	Founding Angel (FA)
Type 1 scientist	Matching. ● Type 1 scientist is willing to commercialize the invention alone or with other technological scientists. ● When an inventor becomes the entrepreneur he/she is convinced that he/she either already possess or can acquire sufficient market and business expertise. No need for an entrepreneurial co-founding partner. ● Strength: Technological expertise ● Critical point: Market and business expertise	No matching. Type 1 scientist is willing to commercialize the invention alone or together with other technological scientists. This contrasts with the SE model where the commercial rights are ceded to an independent entrepreneur (third party).	No matching. Type 1 scientist is willing to commercialize the invention alone or together with other technological scientists. Type 1 scientists are convinced that they either already possess or can acquire sufficient market and business expertise. No need for an entrepreneurial co-founding partner such as a FA.
Type 2 scientist	No matching. Type 2 scientist considers the engagement in a venturing project as incompatible with an academic scientist role. This contrasts with the IE model.	Matching. ● Type 2 scientist considers engagement in a venturing project as incompatible with an academic scientist role and is willing to cede all rights to the invention, to an entrepreneur. ● By definition, the SE strives for commercialization (largely) independently from the technological inventor. ● Strength: Market and business expertise ● Critical point: Technological expertise	No matching. Type 2 scientist is not willing to engage in an university spin-off, but the FA model is based on the idea that the scientist acts as co-founder together with the FA.
Type 3 scientist	No matching. Type 3 scientist is aware of the lack of sufficient resources (e.g. time, money) or capabilities to initiate and run the university spin-off alone and the need for a skilled founding partner.	No matching. Type 3 scientist is unwilling to cede all rights related to the invention to an independent entrepreneur (3rd party).	Matching. ● Type 3 scientist is willing to engage in a university spin-off project with a skilled co-founder. ● By definition the FA acts as co-founder, possesses technological understanding and brings market and business expertise. ● Strength: Technology, market and business expertise ● Critical point: Soft factors

4.3.1. Type 1 scientist and the IE

In several cases, (Type 1) scientists regarded themselves as execution oriented and as not needing a founding partner with business proficiency. This type of scientist acts as co-founder together with other inventors from the research team and, thus, assumes the role of entrepreneur. The specific areas of responsibility and level of engagement in the spin-off can vary among founding team members and the professor/inventor typically assumes an advisory role rather than assuming an operational function, and sits on the firm's board of directors.

Technology. Inevitably inventors who become entrepreneurs are strongly committed to the technology, which is particularly useful for overcoming problems arising during the commercialization process (Franklin et al. 2001; Radosevich 1995). Although Type 1 scientists are open to business venturing and some of the tasks this involves, they emphasized their desire to continue with academic research:

> *If it would take more of my time, then I would lose the fun [related to business venturing]. So for me it is very exciting because it provides me with the chance not just to sit behind the microscope and to do research. […]. But it [business venturing] is not my main driver. I am a researcher, body and soul, and want to remain a researcher.* [Type 1 scientist]

Similarly, other Type 1 scientists and founders stated that, especially in the very early stages of a new venture, there is no need for business experts since the issues that need to be resolved are primarily technological problems, and the technology generally requires further development. Type 1 scientists tend to regard the technology and its originators as being at the centre of a venturing project. A few interviewees expressed a more extreme attitude to the non-inclusion of co-founders other than the inventor team in the early stages, for financial reasons:

> At a startup level you don't have the funding to support different people […] such as a chief technical officer, or a CEO. [Type 1 scientist]

Market and Business. Vohora et al. (2004) describe one of the major problems related to academic scientists becoming entrepreneurs as that typically they do not have the commercial expertise required for successful exploitation. According to the IE model, the academic scientist is responsible for ensuring provision of sufficient resources and capabilities (Rasmussen et al. 2014) to embark on business operations. Our empirical data indicate that, for a team of technological scientists with little or no market and business experiences, overly optimistic assessments about the technological maturity of their inventions and their ability to resolve business issues, are major problems. For example, in describing a previous and failed business venture, one professor told us that:

> *We didn't have a mature enough technology. And so for me the biggest hurdle was how to bring the technology or idea to the level of maturity that would then be more likely to succeed as a startup company. We had an idea, but it was a very general idea and we didn't know exactly what was the best field of application and I think we just jumped too quickly towards investors.* [Type 1 scientist]

One of the most promising ways to address the lack of market and business proficiency associated with the IE model, is to assign one member of the research team to the business side and in this way to accumulate related expertise. Several Type 1 scientists said they had assigned this role to a current or former member of their research team with some affinity for business operations, who was willing to undergo some coaching to gain the required responsibilities (cf. Clarysse and Moray 2004). Although most Type 1 scientists were hesitant about including a third party with a business consulting background, if the person was an alumnus from their technical research group and was known to them, they would be happy to have this involvement. For instance one professor and co-founder stated that:

> *Well one of my Ph.D. students, when he finished here, he went into management consulting for three years. And so he got management experience and education in management consulting and he was coming back [as the CEO of our spin-off]. And I was just discussing here with one of my other students, he also is really getting burned out in management consulting, and we just said:* 'Hey, you know, we've got this idea, we think it might be turning into something.' *And he's a very talented person.* [Type 1 scientist]

While the above extract leads on to a discussion of soft factors related to founding team members, it can be concluded that market and business acumen are the most critical factors associated with the IE model. In almost all cases, the scientists were aware of their significance and the need to mitigate weaknesses.

Soft factors. The interviewed university spin-off founders and also several scientists with entrepreneurial experience (Type 1), assigned higher priority to passionate commitment than to market and business expertise. This seems particularly important for interviewees with entrepreneurial experience, typically based on the IE model. One professor with personal entrepreneurial experiences described it thus:

> *I think obviously more [business] experience is better, but to me [...] the most important thing is to get* passionate *smart people. You learn this [market and business] stuff... - you know you can get coaching here, I think it's available. I mean clearly if you bring in somebody who has done it before, they are gonna help you to avoid a lot of mistakes. But to me it's more about getting people with* passion *who are* willing *to put in extra-hours.* [Type 1 scientist]

So, in line with the findings in Vohora et al. (2004), business experience is seen as an advantage, but intrinsic motivation (Lam 2011) for and engagement in the project are considered imperative as highlighted by several Type 1 scientists and IEs.

4.3.2. Type 2 scientist and the SE

The SE model might be most appropriate for scientists who are not interested in managing a spin-off and who, at best, are open to providing technological advice. As a result of this small personal involvement in the commercialization activity, the empirical data indicate that this type of scientist is relatively indifferent about the ideal characteristics of an entrepreneur who might bring their invention to the market.

Technology. By definition, SEs commercialize academic research results largely independently of their inventors. In contrast to IEs, who have expert knowledge of and strong commitment to the technology (Franklin et al. 2001; Vohora et al. 2004), SEs may lack technological insight (Lundqvist 2014; Radosevich 1995). However, it is necessary for the SE to have some solid technological expertise in the field and to take account of his/her potential weaknesses when building the spin-off team. This is particularly important if the technology has not reached market level maturity and requires further development. In this context, Kassicieh (2011) points out that technical expertise is essential during the product development phase, while other skills, such as familiarity with the market and users, are important in the later market development phase. However, like Filatotchev et al. (2006), Kassicieh (2011) suggests that the separation between these phases can be problematic, especially in the case of technologies with short product life cycles, and may require the actors to work on both stages iteratively.

Market and Business. The main advantage of the SE is expertise in business and market-related aspects, especially in managing the introduction to the market of new technologies from academia (Franklin et al. 2001; Kassicieh 2011; Radosevich 1995). Since market and business are the core expertise of SEs, it can be supposed that lack of market and business competencies is unlikely to be an issue.

Soft factors. Although Type 2 scientists refuse to engage in the commercialization of their research results there was a consensus that they would be open to advisory cooperation with individuals from outside university who took the initiative to contact the scientist and express their interest. However, the individual scientist's degree of personal engagement and contribution differs. Most notably, Type 2 scientists declared to be willing to engage in informal discussions and provide additional research data to interested individuals although stressing their desire for independence, and the obligation of the other party to make decisions and take responsibility about how to proceed in the exploitation process. One scientist with no commercial aspirations stated that:

> *I am pleased to share this information [...] and actually do share it [with representatives of any companies]. I consider this a social responsibility that we are not doing all the [research] things here in an ivory tower, but that we share our knowledge with others, and absolutely free of charge. I make enough money here, so I do not need [to take financial benefits from] it. And I would like to add that* I do not want to be dependent *[on any commercialization project].* [Type 2 scientist]

This interview extract shows that Type 2 scientists tend to follow the norms of open science and have no objection to sharing their technological insights with entrepreneurs. However, because they do not want to be involved personally in the commercialization, the Type 2 scientists interviewed had no explicit requirements regarding external entrepreneurs' characteristics. On the entrepreneurs' side, this requires them to be prepared to manage all the issues associated with the spin-off, which may be difficult if there are technical matters involved.

4.3.3. Type 3 scientist and the FA

The majority of the scientist interviewees said they could envisage engaging in a spin-off project if they had an appropriate partner. For these Type 3 scientists, the FA model would seem a suitable approach. However, unlike the IE and SE models where the inventors or the external entrepreneurs initiate and run the new venture on their own, in matching Type 3 scientists and FAs, it is especially important that the entrepreneurial candidate embodies the characteristics the scientist requires of a founding partner. In the discussion of matching Type 3 scientists in the following sections, we also consider some statements from Type 1 scientists who had acquired venturing experience. This should provide more valuable insights into why a founding partner might be especially useful for scientists.

Technology. Professors with potential entrepreneurial aspirations explicitly emphasized the need for the potential co-founder to have profound technical knowledge in the field "*not to the last scientific or engineering detail, but a deep understanding on what is being commercialized*" [Type 1 scientist]. Several interviewees stressed that this was particularly important for early stage technology spin-off projects where there is a strong focus on handling technical challenges. Numerous scientists described themselves as very technologically driven and would expect a potential co-founder to have a thorough understanding of the technology. The significance of technological expertise was highlighted by a professor who had co-founded two spin-offs, the first with business-oriented partners and the second with other inventors. She stressed that there is a risk of severe problems if a business partner with little technological expertise makes promises to potential customers that are difficult to realize technically. Based on her own university spin-off experience, she said that:

> *We had a very strong business side, with very active and quite experienced business partners, however, they really did not understand the technology. So when they were trying to look for customers, there was a gap and [after meetings with potential customers] we were saying: 'Why did you say that? [Technologically] we can never achieve it.'* [Type 1 scientist]

A solid technical understanding is essential also for presentations and negotiations with other business contacts, such as investors, banks, cooperation partners and customers, in order to grow the company.

By definition, a FA needs technical expertise and professional experience in the relevant area, and has to play an active role in the whole engagement process. To avoid potential customers being promised what would be impossible, and to avoid unreasonable expectations of the FA's , a FA candidate should have several years of experience in research and development in the corresponding technological area.

Market and Business. Although academic scientists may have limited market and business expertise (Visintin and Pittino 2014; Vohora et al. 2004), they might have the ability to identify market opportunities and industrial partners for the further development of the technology to market maturity. Type 3 scientists often need a partner with the market and business proficiency a FA could be expected to possess. Almost every interviewee stressed the importance of business experience that a potential co-founder needs to bring in. Several interviewees mentioned that this did not necessarily include a degree in management which is not proof of the individual's management abilities. As a professor with entrepreneurial experience put it:

> *I do not think that a management education background is decisive, more important is a co-founder who possesses business experiences in the specific [technical] field, which means, for example, that he has already co-founded or managed a startup and is familiar with the business environment which is really very useful in order to create a business network and establish contacts, etc. So, overall, I think management knowledge through education is of course important, there is no doubt. But in the end, the management has to decide about what to do with the technology out of the 1000 application possibilities that they have.* [Type 1 scientist]

As described above, three central entrepreneurial capabilities are: 1) opportunity identification and development; 2) a champion for the venturing process; and 3) ability to attract the resources needed for commercial exploitation of the opportunity commercially (Rasmussen et al. 2011; 2014). Our analysis of the interview data supports these competences and particularly the second one, in indicating that the market and business characteristics which academic scientists most often require of founding partners are: 1) knowledge of the market to enable identification of new business opportunities; 2) having an established business network; and 3) several years of entrepreneurial (or, at least, general managerial) experience in the specific technological field.

The FA engagement process starts with an evaluation of the market opportunities for the invention (Festel and De Cleyn 2013b), and continues to development of the business idea and advancing the venturing process together with the inventor (Festel 2011). Thus, most of the hurdles that academic scientists face in commercializing their inventions are mitigated by the contribution of a FA who will work to progress the project.

Soft factors. In relation to the personal characteristics of the FA, the most critical is passion for the project, understood as a high level of intrinsic motivation to succeed, a hands-on attitude to the work involved, and complete involvement whenever necessary. For FA involvement to be considered a serious option for the scientific inventor, the FA must be able to demonstrate significant commitment of time and effort to the project. The FA must also be acceptable to co-founders and regarded as an equivalent team member and entrepreneurial partner not an external agent such as an investor. This departs from Festel and De Cleyn (2013b) definition which suggests that an FA can be engaged in several (up to a maximum of 5) commercialization projects simultaneously. Based on the results of our study, involvement in five projects would be too much. This number should be corrected downwards, at least for the initial stages of the venturing process when the founders are responsible for all the entrepreneurial activities. One spin-off founder's comment echoed the views of several other interviewees:

> *Such [serial] entrepreneurs, who are doing a thousand other things simultaneously, I see that as somehow problematic. [...] Maybe they put their name on the project, but they are not 100% engaged in the company.* [Founder]

In other respects, our results are in line with Festel and De Cleyn (2013b), who point out that the active engagement of an FA in the very early stages of the venturing process makes the FA more similar to that of entrepreneur and co-founder rather than investor. Building on this, with regard to individual incentives, several interviewees expressed concern over the asymmetric distribution of risk among the members of the founding team, and pointed out that the FA might have access to more sources of income. Different personal objectives might result in different positions and different responsibility for managerial decisions, which could cause tensions among team members.

Several interviewees stressed that the FA should be an entrepreneur, able to manage both simple and more complex tasks and to work long hours, and should have the capabilities required to resolve conflicts and reduce tensions within the company and with external business partners. These requirements were seen as particularly important to those interviewees with personal experience of university spin-off projects as co-founders, technology transfer officers or some other function.

Two spin-off firm founders expressed concern over the age of experienced co-founders, although generally they were in favour of involving an experienced entrepreneur in the spin-off team – "*Often these are people aged, let's say, 60 or older and how well this would fit with the rest of the team would be my only concern*" [Founder].

Also important in relation only to the FA model is the *bonding process* between the academic scientist and the FA. There are three possible ways how FAs can establish contact with academic scientists that emerge from our interview transcripts: First, direct contact with the scientist as the result of a publication or press release. Second, through an accidental meeting, perhaps at a social event. Third, by making it known among faculty members that entrepreneurial partners, in form of FAs, are present. The first two strategies are short term, while the last is more long term. However, the overriding precondition for a venturing process is a level of trust on both sides. The scientists interviewed generally agreed that initial discussions should be informal and non-binding to leave each party free to make a decision about whether or not to proceed with a spin-off project.

Several scientists declared themselves to be generally open to commercialization projects with external entrepreneurs who initiate discussion or whom they meet at an informal social event. One interviewee said that:

> *If I had to take the initiative, then I would be overloaded with things that I have to do and I would have to reduce many of my activities and set priorities accordingly, but this is very difficult. However, if the Founding Angel were to initiate the process, maybe through an informal discussion, and I do not have to make a commitment, and do not have to demonstrate anything, but just talk about the opportunities [...] this might motivate me and I would come up with some ideas.* [Type 3 scientist]

Alternatively, the FA might work to establish an ongoing relationship with faculty members so that the scientists know who to contact should they want to discuss a promising research result with an experienced business person. One of our interviewees described this bonding process as follows:

> *If it was more informal and I had some potential [founding] partner known to the department and I could just pick up the phone, call him and say: 'Hey, I possibly have a business idea. Come by and let us discuss its potential opportunities this afternoon.'* [Type 3 scientist]

To summarize, the FA should have simultaneous involvement in a small number of university spin-off projects in order to allow proper management of the full range of entrepreneurial tasks. The potential FA must provide evidence of solid technical and business expertise, entrepreneurial skills and available time. The interview data suggest that the bonding process is probably one of the most critical points associated with the FA model, and that academic scientists have very different ideas and preferences in this respect. However, there was a consensus that the bonding process between the entrepreneur and the FA should be based on initial non-binding discussions and freedom to decide about whether to embark on a venturing project with a specific FA.

5. Discussion

In the search for an appropriate co-founder, it is remarkable that those actors with more entrepreneurial experience put greater emphasis on the characteristics related to soft factors and individual fit with other founding team members. In addition to bringing market and business expertise, potential co-founders must be able to communicate their conviction and dedication to a potential project. Other attributes required by a co-founder, which should be prerequisites for potential involvement, include solid technical expertise, a similar risk profile to the other founding team members, and similar personal characteristics such as age. These factors may not have a direct effect on the project, but their absence could raise intra-team tensions (cf. Clarysse and Moray 2004; Foo et al. 2006).

In the following sections we first discuss the implications of our research results for the existing literature. Subsequently, we present recommendations for the design of future academic entrepreneurship policies.

5.1. Implications for the existing literature

The investigation of the entrepreneurial models based on the needs of academic scientists contributes to the literature in two ways. First, the route to commercializing university-generated knowledge through the inclusion of external entrepreneurs in a venturing project is considered a promising alternative to the predominant IE model, but has been rather ignored (Politis et al. 2012). Models such as the FA approach have been examined in isolation (e.g. Festel and De Cleyn 2013a; b), and the SE approach has been compared (e.g. Franklin et al. 2001; Kassicieh 2011; Radosevich 1995) to the traditional IE (**Table 1**), but not in a comprehensive way including all three entrepreneurial models. Second, the previous literature focuses on the external entrepreneur's perspective (e.g. Festel and De Cleyn 2013b; Kassicieh 2011) or on technology transfer offices (e.g. Festel and De Cleyn 2013a; Franklin et al. 2001), but does not connect the views and needs of scientists with the existing entrepreneurial models. Clarysse et al. (2011a) highlight that individual-level attitudes of scientists have been largely unexplored in the academic entrepreneurship literature, and found that individual attributes are central predictors of entrepreneurial activity. The present article examines which of the three entrepreneurial models might best suit individual types of scientists and provides a better understanding of the challenges faced by academic inventors in bringing their inventions to the market.

Our analytical linking of scientists' perspectives to the three entrepreneurial models discussed in this paper, reveals that they can be matched based on the scientist's view on a venturing project. For scientists with little interest in commercial activities, the SE model might be the most appropriate approach. At the other end of the continuum is the IE approach, which would seem suitable for those scientists who want to bring their discoveries to market on their own. However, the breadth of the spectrum between these two extremes suggests the need for an intermediate approach. The importance of an intermediate approach is substantiated by fact that most of our interviewees explained their lack of venturing project activity as due to lack of entrepreneurial support. The FA model, which matches the scientific inventor to an entrepreneurial co-founder, might be a potential solution. This result is in line with Lockett et al. (2003), Franklin et al. (2001), and Lundqvist (2014), who conclude that an approach that combines inventors and entrepreneurs is likely to be more effective since both parties contribute particular strengths - either technological or business and venturing. This paper suggests that external entrepreneurs could add value, and extends the theory by providing further empirical evidence (cf. Visintin and Pittino 2014; Lundqvist 2014; Franklin et al. 2001). For academic scientists, the FA approach (i.e., collaboration with an external entrepreneur) is one way to gain access to complementary resources such as other technologies required for commercialization, brand, organizational knowledge and, especially, manufacturing capacities (Teece 1986). Prior studies (e.g. Teece 1986; Somaya et al. 2011) suggest that it is critical for scientists to get rapid access to these complementary resources in order to profit from their innovations. Scientists can establish a solid base of complementary resources either on their own (via the IE approach) or with the help of an entrepreneurial partner (via the FA approach). In contrast, SEs are solely responsible for acquiring complementary resources. A lack of complementary resources may lead to a major share of the commercial profits from the invention going to followers/imitators (Teece 1986). However, due to the potential financial profits resulting from the commercialization an academic research discovery, both the affiliated university (typically the owner/assignee of the intellectual property) and the scientist (as the beneficiary of a financial 'inventor bonus') should be aware of all three approaches. In this context, the present study adds to the literature on how academic originators of the intellectual property can benefit from their research discoveries (e.g. Teece 1986; Agarwal and Shah 2014; Dedrick and Kraemer 2015; Jacobides et al. 2006).

Similar to the observations in Jain et al. (2009), all the scientists interviewed emphasized that their primary focus was on maintaining their focal academic role identity. However, the results indicate varying degrees of willingness to adopt a secondary entrepreneurial role. Those researchers who see their mission as devotion entirely to academic teaching and research (Type 2) are either unable or unwilling to adopt such a secondary role at all. Nevertheless, our results suggest that besides these (Type 2) scientists there is a number of other scientists who either have already assumed a secondary entrepreneurial role (Type 1) or who are stuck in in the preparation/decision phase (Type 3) of considering the secondary role of entrepreneur. In the case especially of Type 3 scientists, who feel unable to commercialize their discoveries on their own and who do not want to pass on their invention to others, the FA approach seems to be particularly suitable. The FA approach is characterized by its design that enables scientists to preserve their primary academic role identity whilst having an involvement in the commercialization of an invention and, thus, developing a supplementary entrepreneurial role.

This study adopted an inductive methodological approach (Miles and Huberman 1994; Strauss and Corbin 1998; Glaser and Strauss 1967) based on interviews with 18 professors from different university departments, and insights gained from 16 entrepreneurial actors. To our knowledge, this is the most comprehensive qualitative research study on the deployment of different entrepreneurial approaches for the commercialization of academic research results. We have shown, that our sample of professors, depending on their views, can be matched to an existing entrepreneurial model.

Universities are heterogeneous and need differentiated technology transfer policies depending on their research intensity and other factors (Hall et al. 2014b; Siegel and Wright 2015; Rasmussen and Wright 2015; Huyghe and Knockaert 2015); similarly, at the more micro-level, the differences in scientists' attitudes to entrepreneurialism call for different policy approaches as discussed in the next section.

5.2. Implications for policy makers

The study has some implications for the design of future policies to promote the transfer of technology from academia. Most university and public initiatives to stimulate technology transfer and support spin-offs, assume that the commercialization activity is undertaken by the scientific inventor. Although the technology transfer officers interviewed agreed that use of external entrepreneurs, and especially linking inventors and FAs, was a promising mechanism to enhance technology transfer in several situations, they said that, so far, this route had not been explored. Our qualitative analysis of the interviews with a range of actors from different fields in the context of technology transfer from academia, indicates a continuing low level of awareness about the targeted deployment of entrepreneurs from outside university in the very early stages of a spin-off project. Why external entrepreneurs tend not to be considered in current policies is due to a lack of awareness and understanding about which entrepreneurial approach is appropriate for which situation, rather than general opposition to such approaches.

Universities keen to use external entrepreneurs need to ensure that the relevant actors (i.e. technology transfer officers, scientific inventors) have a basic understanding and awareness of the existence of alternative entrepreneurial models. A general awareness of the various models available is important even for those scientists who might be reluctant to engage personally in an entrepreneurial project (Type 2 scientists) and who see their mission as confined to academic research and teaching. When it comes to applying for a research grant it is typically advantageous for scientists to present a clear route to market – and this plan should be based on an appropriate entrepreneurial approach (**Table 7**). Our study provides an overview of the existing entrepreneurial support models and their application possibilities. These models can be used as complements or alternatives to the practices that currently dominate technology transfer activities. This study offers some guidance about which of the staged entrepreneurial support models would be most appropriate in the particular prevailing circumstances, allowing those involved to make informed choices. In line with Rasmussen et al. (2014), academic policy makers should strengthen their competencies to identify and further develop promising venturing opportunities. In this context, the ability to evaluate whether the best avenue to commercialization of a specific technology is the scientific originator (IE model), a mixed team of scientist and entrepreneur (FA model) or use of external entrepreneurs, acting largely independently of the inventor (SE model), is crucial.

Analysis of the empirical data highlights the important role of the university in providing active assistance and instilling an overall attitude to entrepreneurial activities. The extant literature shows that the views of departmental and university level managers on spin-off projects generally as well as personal engagement alongside an academic university role, are of crucial importance for the scientist's decision to engage in entrepreneurial activity (e.g. Rasmussen et al. 2014; Jain et al. 2009). This applies especially to the case of non-tenured faculty who want to continue in academia (Wright 2012; Clarysse et al. 2011a). In line with this literature, the interview data obtained from the present study support the notion that many scientists are reluctant to engage in spin-off projects if they are seen as disruptive to department or university relationships. Two frequent concerns that the interviewed scientists expressed were related to the time commitment related to a spin-off project and to conflicts arising from additional financial compensation for the academic research activity based on university resources. The reluctance to engage in commercialization might be mitigated by a university environment supportive of spin-off activities (cf. Rothaermel et al. 2007; Clarysse et al. 2011a). Clear policies should be implemented on secondary entrepreneurial engagements, covering aspects such as time commitment, use of student human resources, and revenue split between university and scientist based on the ownership of the underlying intellectual property rights. In addition, consideration could be given to rewarding academic scientists' technology transfer efforts and venturing projects through tenure and promotion decisions. Our results strengthen the conclusions in Siegel et al. (2003) that university policies should signal that business venturing is appreciated by the university and that a considerable part of the workload related to marketing and business operations could be shouldered by an external entrepreneur.

6. Limitations and further research

There are some important limitations related to the design of this research which apply also to the study by Jain et al. (2009) on role identity change in academic entrepreneurs at a US university. First, all the cases examined in this paper and most of the interviewees were from one large technical university in Switzerland that has well-established routines to support the commercialization of new technological inventions, for example, training lectures for students, coaching for individual founder teams, a technology transfer office with experienced staff, and proven business venturing processes. Thus, the findings in this paper may not apply equally to other university settings that do not benefit from similar support, and where the management of conflicts of interests is less clearly defined. Shifting from a university to a country context, we would acknowledge that our sample focuses only on professors in Switzerland, and that the results may not apply equally to academic scientists in other countries although most of our interviewees have diverse international private and/or professional backgrounds. We recommend further cross-cultural and comparative studies to examine the usefulness of the entrepreneurial models for other universities and other national contexts. Second, the cases are based on scientists who have spent the major part of their working life in academia. Using longitudinal data, it would be interesting to compare and contrast the views of scientists in academia with those of scientists who left academia in order to found a university spin-off and who have several years of business venturing experience.

We would encourage future research to scrutinize the effectiveness of the proposed theoretical matching. In-depth, longitudinal research of nascent university spin-offs would be useful to clarify the critical elements in effective collaboration between scientists and entrepreneurs. Longitudinal research could also uncover which other possible contextual and individual-level variables of both scientists and entrepreneurs need to be considered for the matching. Also, comparative research on a set of existing spin-off companies could investigate which combination of scientist type and entrepreneurial model (**Table 7**) performs best in terms of team viability (cf. Clarysse and Moray 2004; Foo et al. 2006), growth, and revenues. Lundqvist (2014) provides a comparative analysis of the IE and the SE approaches based 170 ventures incorporated between 1995-2005 and shows that those ventures using the SE approach performed significantly better for growth and revenue compared to those adopting the IE approach. Further studies are needed to include the FA approach in the comparison in order to obtain a more holistic view of the strengths and weaknesses of all three approaches and their alignment to the individual attitudes of the academics. We would encourage mixed-methods studies, combining insights based on qualitative and quantitative data on spin-offs in order to obtain a more thorough understanding of the effectiveness of the matching.

7. Conclusion

This study set out to provide a deeper understanding of the individual-level characteristics that matter when choosing an entrepreneurial model to transfer scientific findings to industry through a new venture. Although in the literature and in practice there are a few approaches involving entrepreneurs from outside the university, most technology transfer initiatives are based on the idea that it is the scientific inventor who brings a research discovery to the market.

The present study contributes to the literature and to practice by investigating the perspectives of academic scientists and their views of existing entrepreneurial models. The results of this study indicate that there is a need for different entrepreneurial approaches. There seem to be two extreme positions of inventors who personally assume a (secondary) entrepreneurial role, and scientist inventors who are not interested in any kind of business venturing activity. These positions seem to be in line with the IE and SE models respectively. However, our analysis indicates that there are many scientists between those two extremes and who regret the absence of an appropriate approach to get a new venture off the ground. They include the large proportion of scientists who are unwilling to cede all the rights to their invention to another party, and lack of entrepreneurial support is impeding the development of technological and commercial potential.

The FA model might be appropriate to support scientists with a potentially commercializable technological discovery and a desire to exploit it, but who lack the market and business expertise required to drive the project by themselves. The matching of scientists' needs to the FA model reveals that the critical point is whether the FA candidate's soft factors, such as entrepreneurial commitment, risk profile, age, are considered by the technical scientist to be suitable. In relation to the bonding process, our results suggest that academic scientists are cautious and require a degree of familiarity with the FA, ideally via well established relationships with other faculty members.

Acknowledgements

The author is grateful for comments from Stefano Brusoni, Nicole Rosenkranz, and Cynthia Little on previous versions of this manuscript.

Paper APPENDIX

Tables 8-10.

Table 8: Interview guide used to interview the technical scientists in the case study.

Category	Example questions
Founding process	What is your impression about the commercialization of new technologies in your area of research (exhaustions, deficiencies)? What do you regard as the main hurdle to founding your own company? Under what condition would you found a company? If you had an innovation with commercial potential – would you be motivated to found a startup? If no, would your decision change if there was an experienced partner who would manage the business/financial topics before and after foundation?
Personal background	Was there any patent (application) based on your research? If yes, how did you use it/them? Do you have any innovations in your research pipeline with commercial potential? What are your plans for them? Are external companies involved in your research (cooperation partners)? If yes, what is their role? Do you already have personal business/entrepreneurial experience? If yes, what do you consider are benefits?
Financing process	How do you think you could attract enough money for foundation and early stage from investors/banks on your own? Do you have a network of potential early-stage investors to attract sufficient financial funds? If yes, can you describe your relationship with them? Can you describe the financing process of the previous spin-off projects from your department?
Business management	What is your view of an experienced partner who would take responsibility for business/financial topics? What qualifications & characteristics should this business focused founding partner have? How much time per week can you spend on entrepreneurship alongside your academic activities? What is your role in the spin-offs from your laboratory?

Table 9: Interview guide used for interviews with spin-off founders in the case study.

Category	Example questions
Founding process	Can you please give a brief summary of your company and its products? What do you regard as the main hurdles to founding your own company? Would you found one again? Who was the driving force/key person in your founding team who took the initiative to found the company? Who prepared the business plan and why was he/she chosen? Were there any problems? What are the qualifications/disciplines of the specific spin-off founding team members?
Personal background	Did you have previous business/entrepreneurial experiences? If yes, what do you consider are the benefits? Was there somebody in your family or a good friend with business/entrepreneurial experiences who supported you (Dos/Don'ts)? What was your motivation to found the company? (money, passion, technical challenge, etc.?) What step in the founding process was most challenging? (from an ex-ante and ex-post perspective)
Financing process	Where and how did you attract your funding? (network with early stage investors?) Who is responsible for attracting funding for the company (CFO)? What sources did you use at the beginning vs. now? Is a Business Angel or VC involved in your startup? At what stage did they enter? What is their role? Financially/Operationally helpful? In your eyes, is it better to include a management guy from the beginning or send a technical guy for management coaching? Why?
Business management	How much time per week do you spend on management tasks and how much on technical tasks (ratio)? What is the result if you compare your ex-ante expectations about the balance between management or technical tasks with the actual situation since foundation? What would you change/improve/avoid if you founded another startup? What did the work sharing among founders look like at the beginning and how did it develop over time? What qualifications & characteristics should this business focused founding partner have?

Table 10: Interview guide for interviews with technology transfer officers in the case study.

Category	Example questions
General background	What are your fields of activity and what services do you offer? What disciplines generate the highest number of academic spin-offs and technology patents? What are the qualifications/disciplines of the specific spin-off founding team members?
Founding process	What in general are the main hurdles before & after foundation? Who prepared the business plan and market analysis? What is the general founding team composition? (number, qualifications, external coach/entrepreneur) Who in the spin-off founding team is your main contact person and who would you regard as the driving force? In how many cases is an experienced business person a member of the founding team? What are the benefits?
Financing process	How do the spin-offs attract financial funds before foundation and in the early stage? What are the main characteristics to consider in the evaluation of startups? How are the results validated? By whom and by which method is the startup's pre-money valuation usually performed?
External entrepreneur	In general, do you perceive a benefit from the involvement of external entrepreneurs (FAs) as co-founders? If yes, why? Is there a better operational management / success rate if an experienced entrepreneur is member of the founding team? Why? What qualifications/characteristics are required from FAs? Which are the areas for potential conflicts? How should the scientists & FAs be aligned? Shareholder structure? Work sharing?

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Paper 2

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Is value in the eye of the beholder? An empirical study of how entrepreneurs, managers, and investors evaluate business opportunities at the earliest stages

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Abstract

Existing research suggests that individuals occupying different professional roles vary in their "opportunity templates", and may thus deviate in their evaluations of a given business opportunity. This paper advances our understanding on how evaluators vary in their assessments of business opportunities in two very early phases by conducting a comparative analysis of three stakeholder groups that are crucial to new ventures: entrepreneurs, managers, and investors. We analyze a unique dataset of 693 business ideas and 379 business-plan proposals submitted to a nationwide startup competition held in Switzerland. Our linguistic analysis reveals heterogeneity in opportunity evaluations between groups with different types of professional roles. However, this divergence in individuals' evaluations does not emerge at the earlier business-idea phase, but only at the later business-plan stage. The study provides empirical evidence that individuals' professional role makes them more sensitive to certain aspects of a given business-plan proposal.

Keywords

startup opportunity evaluation; professional role; heterogeneity; business plan competition; opportunity template; linguistic research

1. Introduction

In this paper, we explore how professional roles affect individuals' *evaluation* of early-stage business opportunities. To evaluate business opportunities, individuals employ mental "opportunity templates" (Barreto, 2012): schemas or knowledge structures that impose meaning on the information available (Dutton and Jackson, 1987; Walsh, 1995). Much empirical evidence suggests that opportunity evaluation varies with individuals' professional role (e.g. Busenitz and Barney, 1997; Baron and Ensley, 2006; Mason and Stark, 2004; Williams and Wood, 2015; Franke et al., 2006; 2008). However, regarding external evaluations of new ventures, little is known about the *extent* to which opportunity templates vary among people occupying different professional roles. More specifically, we know little about the sensitivity of professional groups to *particular attributes* of an opportunity (Gruber et al., 2015).

In the same context, literature provides few insights into dynamic changes in opportunity templates between *stages* of new-venture evolution. In the very early phases — typically those with greatest uncertainty, when claims made by venture teams are difficult to verify — outsiders' subjective impressions play a more central role (Chen et al., 2009; Zacharakis and Shepherd, 2001). In this vein, authors have emphasized the significant influence of "language in conceptualizing venture opportunities and in influencing stakeholders about the feasibility of a venture" (Clarke and Cornelissen, 2011, p. 776). Language is intertwined with thought, making it a "key mediating mechanism or device in influencing the cognitions of others" (Clarke and Cornelissen, 2011, p. 776). Thus, heterogeneity in opportunity evaluation may be related to linguistic cues: verbal descriptions may be captured and processed differently by readers' opportunity templates, leading to evaluation differences.

Typically, one of the first occasions for external evaluation is a startup competition. Startup contests have proliferated in recent years (Kirsch et al., 2009), and many teams rely on them to refine, market, and finance their ideas (c.f. Grichnik et al., 2014; Foo, 2010; Foo et al., 2006). A unique feature of startup contests is that judges are drawn from diverse professional roles. The ability to convince individuals such as other entrepreneurs, managers, or investors is critical to new ventures, whether to win startup competitions, raise funds, seek strategic partnerships, attract co-founders, or for other reasons.

We extend recent research by Gruber et al. (2015), who found evidence of heterogeneity in opportunity evaluations by individuals having different educational backgrounds. We investigate the evaluations of a comprehensive group of jurors in a major Swiss startup competition at two different stages: the nascent business-idea stage, and the more mature business-plan stage. This setting enables us to delve deep into the relationships between opportunity stage and opportunity templates. Relying on data on 1072 business opportunities submitted between 2004 and 2014, we connect the linguistic descriptions (i.e., linguistic cues) in these documents with ratings by three types of jurors (i.e., entrepreneurs, managers, and investors). The research question we seek to answer in this project is to which extent is the relationship between linguistic cues and business opportunity evaluations contingent on the evaluator's role?

Using a novel psycholinguistic approach on real-life ideas and proposals enables us to draw inferences on people's opportunity templates and their sensitivity to particular attributes.

Our results show that professional role does influence business-opportunity evaluation at the business-plan stage, but *not* at the idea stage. Contrary to received wisdom, the results indicate that investors are strongly averse to details on rewards in a business-idea proposal. For both, business ideas and plans, we find empirical evidence that entrepreneurs are more sensitive to power cues than managers and investors.

These results are relevant for literature, startup founders, and startup competitions alike. Research should control for both, professional differences among evaluators and the stage of the business opportunity. For startup founders, our results imply that only from the business plan stage, the proposal needs to be customized depending on the role of the target audience (e.g. to financial investors, or representatives from potential corporate partners). Organizers of startup competitions should take into account professional role effects when assembling a team of jurors and assigning jurors to the specific projects. Furthermore, organizers of a startup competition, but also coaches on entrepreneurship, should discourage (would-be) founders to speculate on (financial) rewards, especially in the business idea phase.

2. Background

2.1. Business opportunities and the difficulty of evaluating them

An opportunity results from competitive imperfections in product or factor markets, which generate the potential for economic wealth creation (Alvarez et al., 2013; Venkataraman, 1997; see Davidsson, 2015 for a review). Due to the multidimensional nature of a business opportunity, evaluating its inherent value largely draws on subjective judgments and the cognitive ability to recognize potential (Baron and Ensley, 2006; Krueger, 2007; Baron, 2007). For external actors in particular, the evaluation of a new venture is difficult due to the lack of generally accepted evaluation schemes and verifiable information (Brush and Vanderwerf, 1992; Gruber, 2007; Shepherd et al., 2003). Compared to startups, scrutinizing the potential of business opportunities is even harder, as there is only a business idea — sometimes supplemented by a prototype or an initial concept study. Drover et al. (2015) point out that the difficulty of assessing a new venture becomes especially salient in venture-capital (VC) screening. Here, VCs must quickly and efficiently discern which opportunities merit embarking on the due-diligence process, which requires substantial resources (Chan and Park, 2015; Kirsch et al., 2009).

A positive subjective judgment is typically pivotal in prompting potential entrepreneurs to take action (Wood et al., 2014). Entrepreneurs (Fiet, 2007; Krueger, 2007; Williams and Wood, 2015), as well as other actors such as investors (Mason and Harrison, 2002; Shepherd et al., 2003; Shepherd et al., 2000;

Wright and Robbie, 1996) and managers (Gruber et al., 2010) connect, interpret, and finally evaluate information by imposing their *business-opportunity evaluation template* (Barreto, 2012).

2.2. Business-opportunity evaluation templates

Individuals faced with business opportunities typically arrive at different decisions because of their filtering, weighting, and interpretation of a given set of information, based on their different background knowledge and their point of view (e.g. professional role) (Foss and Klein, 2012, pp. 78 f.; Lachmann 1977, p. 67; Casson and Wadeson, 2007). Along with this process goes the evaluation of the business opportunity by imposing one's opportunity template. Opportunity templates consist of schemas or knowledge structures that people impose to give meaning to information available on a specific item (Dutton and Jackson, 1987). People use opportunity templates to translate often incomplete and equivocal data into understanding, and estimate the probabilities of possible outcomes (Barreto, 2012).

The processing of the information cues often follows an "automatic" procedure (Dutton, 1993; Barreto, 2012). So, once an opportunity is identified and a sufficient set of relevant information on it is available, people devote "limited cognitive effort or expenditure of attentional and analytic resources" (Dutton, 1993, p. 341) when imposing their individual opportunity templates (Barreto, 2012; Gruber et al., 2015). For example, given the lack of robust measures to assess a new venture directly, and limited time to interpret the business plan[11], Chan and Park (2015) found that VCs frequently respond to more visible and accessible features, such as images and colors.

Yet, little is known about the heterogeneity of opportunity templates among individuals from different professional groups, or the extent to which psycholinguistic cues describing certain attributes of an opportunity are recognized in readers' business-opportunity evaluation templates (Barreto, 2012). Nor do we know which aspects of opportunities are especially appealing to people with different professional roles (Gruber et al., 2015). Whereas Barreto (2012) studied the opportunity template for would-be entrepreneurs, Gruber et al. (2015) adopted the concept to examine heterogeneity in the evaluation of business opportunities through a choice-based conjoint analysis of technologists, managers, and entrepreneurs. Linking the observable parameters – linguistic cues as inputs on one hand, and ratings as outputs on the other – enables us to draw inferences on peoples' opportunity templates. But first, it is important to review current knowledge on how individuals' professional role shapes their opportunity template.

[11] In literature there is also a controversial debate on the value of formal business planning (e.g. Brinckmann et al., 2010; Gruber, 2007; Kirsch et al., 2009; Delmar and Shane, 2003). Some new ventures may decide not to prepare a formal business plan document due to the time commitment involved, limited strategic flexibility, and hard-to-predict future developments—especially when facing high degrees of uncertainty. Instead, new ventures may decide to follow a rather erratic learning approach and focus on strategic flexibility (Brinckmann et al., 2010; Lange et al., 2007).

2.3. The impact of the evaluator's professional role

Studies have found empirical evidence that peoples' professional and educational context influences their views on business opportunities (e.g. Gruber et al., 2015; Wood et al., 2014; Gruber et al., 2010; Kenney and Patton, 2015). Opportunity templates also help them select and weight certain attributes. However, while some research compares the views of actors within the same professional domain (e.g. types of financial investors in Mason and Stark (2004), Knockaert et al. (2010), and Pontikes (2012)), there is very little literature that compares the views of the groups relevant to a startup — namely, entrepreneurs, managers, and investors. Such an analysis could draw out implications for founding teams on how to tailor their proposals to different target audiences.

Just as role shapes peoples' opportunity templates, so it affects their focus on particular opportunity attributes. Different readers will rely upon observable cues related to their own focal opportunity attributes. Below we review extant literature on attributes that are particularly sensitive to different groups.

2.4. Important business-opportunity attributes for external evaluators

McClelland (1961)'s theory of motivation suggests humans are motivated by power, achievement, and affiliation. Pennebaker et al. (2015) added risk and rewards, and labeled the factors "drives". Previous research indicates that these drives are revealed through written documents and are interpreted differently by different individuals (Schultheiss, 2013). We focus on the drives transmitted in business-planning documents, which represent cues that evaluators feed into their opportunity templates. Fauchart and Gruber (2011) have shown that varying drives can result in different types of startup founders; instead, we seek to understand how external evaluators perceive these drives in business planning documents.

The *risks* and *rewards* of a business opportunity are of interest to all stakeholders to some degree (Vesper, 1996, p. 241). Studies have found that riskier opportunities lead to higher financial returns, over and above founder characteristics (Dencker and Gruber, 2015). Other important attributes relate to *achievements* that have been accomplished or are defined as future milestones. In their analysis of VCs' evaluation criteria for new venture proposals, Macmillan et al. (1985) identified several items that are related to past and future achievements associated with the product/service, the market, or the financials. For example, achievements can be associated with successfully developing a prototype (Petty and Gruber, 2011), obtaining a patent (Haeussler et al., 2014), competitive rivalry in the target market (Shepherd et al., 2000), or first sales and resultant cash flow (Gruber et al., 2015). The dimensions of *achievement, power, and affiliation* also appear in various other studies as essential characteristics for vetting new ventures (e.g. Olson and Bosserman, 1984; Miner et al., 1989; Hessels et al., 2008; Apospori et al., 2005). For instance, Wainer and Rubin (1969) investigate the influence of entrepreneurs' needs for achievement, power, and affiliation on new-venture performance, finding that a high need for achievement and a moderate need for power have a positive effect.

Drawing on all these studies, we focus on cues related to affiliation, achievements, power, reward, and risk. These five "drive" variables in the linguistic research taxonomy represent five distinct opportunity attributes, each transmitted by a certain set of linguistic cues in the business-idea/business-plan proposal (**Table 1**).

Table 1: Exemplary words from the LIWC dictionary for the five* study variables.

Dimension	Examples of words included in dictionary
Affiliation	alliance, ally, collaborate, fellowship, group, partner, relationship, team
Achievement	accomplish, attain, better, create, earn, gain, improve, lose, solve, successful, win
Power	ambition, boss, control, employer, expert, fame, lead, powerful, superior, obey
Reward	benefit, bonus, earn, gain, get, obtain, prize, profit
Risk	averse, careful, danger, difficult, doubt, fail, lose, unsecure, worst, wrong

* Together, these five variables make up the main category "drives" as specified in the LIWC dictionary.

3. Hypothesis development

3.1. Baseline hypotheses

This study aims to investigate the influence of an individual's professional role on their evaluation of a given business opportunity. We expect that professional role influences an individual's view of a business opportunity, and thus their business-opportunity template. This, in turn, may lead to heterogeneous preferences and judgments about a given set of opportunities among groups of individuals.

To test our first set of hypotheses, we replicate the baseline approach of Gruber et al. (2015) by using a database comprising different groups to explore how individuals with different roles systematically differ in their evaluations of business opportunities. Various studies have already found a relationship between individuals' evaluation decisions and their role in management and entrepreneurship (e.g. Busenitz and Barney, 1997; Gruber et al., 2015; Williams and Wood, 2015; Tan, 2001; Laureiro-Martínez et al., 2014) or different areas of finance (e.g. Mason and Stark, 2004). Therefore, we hypothesize:

> *Hypothesis 1a. Individuals with diverse professional roles differ in the evaluation of given business opportunities.*

Based on the results of the general relationship, we investigate whether such discrepancies become more or less pronounced when evaluating an opportunity at different maturity stages, by comparing the judgments of business ideas versus business plans between the different groups of evaluators. As with most similar studies, Gruber et al. (2015) admit that their analysis is limited by its static focus on a single process stage. Typically, a business idea evolves over time. The initial, roughly described idea gradually becomes more detailed, resulting in a business plan with more precise and in-depth information. Based on studies using archival, non-experimental data (Foo et al., 2005; Foo, 2010), the business-idea and business-plan phases are deemed to be the earliest stages of the entrepreneurial journey at which the opportunity can reasonably be judged by outsiders.[12] Just as the opportunity evolves and becomes more detailed, so the jurors' opportunity template itself, and its focal points (input parameters), is likely to change as the proposal matures.

Both business-idea and business-plan documents vary in terms of length, which probably creates some corresponding fluctuations in the number of cues they contain. In general, however, business-idea documents (about 5–6 pages) are usually shorter than business plans (20–30 pages). This results in different numbers and proportions of certain cues, making the influence of specific cues more salient and thus leading to different judgments. For example, the limited information and cues available to evaluate business ideas might prompt individuals to draw on a simpler, more generalized opportunity template than the one used for business plans.

For the purpose of this study, we leave aside the question of whether the template is dynamically created or dynamically chosen (i.e. whether the *template itself* changes, or whether it is *chosen* from a range of pre-existing templates). Instead, our focus is on how the heterogeneity of the three professional groups in terms of opportunity templates evolves over time, regardless of the underlying process. In the context of evaluating opportunities at different stages, for instance, evaluation behavior might vary across all groups of evaluators, or only for one particular group.

Following these lines of reasoning, we argue that opportunity templates of each professional group is exposed to dynamic changes. Thus, we propose:

> *Hypothesis 1b. Individuals with diverse professional roles evaluate business opportunities differently depending on the opportunities' stage.*

Having tested for general differences among the three types of evaluators, we next aim to shed light on the degree of similarity or contrast between groups (i.e. which groups are more alike in terms of evaluation). In this context, we examine the distances between the groups — specifically, whether certain pairs are more proximal than others. Based on their executive roles, we would expect a higher

[12] Even in these early stages, vetting the opportunity may be a challenging task due to limitations in the available data. On this, Gruber et al. (2015, p. 222) point out that there might be some "early-stage settings in which the quantity and quality of information pertaining to a particular opportunity attribute may (still) be too low for the agent to accomplish judgemental inferences based on his/her opportunity template".

proximity in terms of opportunity template between entrepreneurs and managers, and a more distinct judgment by individuals with an investment position. There is information asymmetry between entrepreneurs (e.g. Kirsch et al., 2009; Murnieks et al., 2011; Dixon, 1991) and firm managers (e.g. Cohen and Dean, 2005; Aboody and Lev, 2000) on the one hand, and operationally inactive investors on the other hand. This asymmetry may encourage entrepreneurs and managers to take high risk/high (potential) return decisions with investors' resources (Shane, 2005, p. 166). Moreover, previous research mostly compares the personality traits of entrepreneurs and managers (e.g. Busenitz and Barney, 1997; Williams and Wood, 2015), but seldom compares either of these groups with investors. Along these lines, we posit:

> *Hypothesis 1c. Individuals with managerial and entrepreneurial roles evaluate a given business opportunity in a more similar way than those with investment roles.*

3.2. Entrepreneurial, managerial, and investment role

Entrepreneurial role

Definitions of the term "entrepreneur" vary (Brockhaus, 1980), but in this study entrepreneurs are individuals who have (co-)founded their own company; who subsequently engage in an operational role in building up its business activities; and who assume the risk associated with the business. As a result, entrepreneurs possess first-hand experience of what it takes to start and run a new firm (McGrath and Macmillan, 2000; Gruber et al., 2015). Whereas investors might also have co-founded a company, entrepreneurs typically do not have a primary or secondary role in an investment firm that manages other peoples' financial assets. Among other insights into the characteristics of entrepreneurs, Sexton and Bowman (1985) found that they tend to prefer autonomy (regarding self-reliance, dominance, and independence), resist conformity, and have a low need for support. Other studies go even further, and discuss the need for power as a motive to become self-employed (e.g. Wasserman, 2012, p. 32 f.). But whereas the power motive in terms of entrepreneurial motivation is often examined (Hessels et al., 2008; Olson and Bosserman, 1984) — sometimes under the term "locus of control" (e.g. Lee and Tsang, 2001; Sexton and Bowman, 1985) — the empirical evidence on whether entrepreneurs' power motive is more positive than managers' is inconclusive (Apospori et al., 2005; Sexton and Bowman, 1985). Over the past decades, some studies have found a range of attributes on which entrepreneurs differ from managers (cf. Shane, 2005; Laureiro-Martínez et al., 2014). For instance, Busenitz and Barney (1997) noted that, under conditions of environmental uncertainty and complexity, entrepreneurs are more likely than managers in large organizations to use rules of thumb, and are shown to have higher overconfidence bias.

From an outside perspective, especially in the early phases, the entrepreneurial founder(s) have a predominant position (Franke et al., 2008; Foo et al., 2005). Entrepreneurs have primary responsibility for all operational and strategic tasks, and act as contacts for external partners and investors. Based on this, entrepreneurs possess unique insider knowledge (Sexton and Bowman, 1985) and have the control over the information flow to potential investors (Kirsch et al., 2009). Therefore, both hierarchy and information asymmetry bolster entrepreneurs' position of power.

Taken together, these arguments indicate that the power motive is key for entrepreneurs who have authority over a venturing project, and we also expect external entrepreneurs to be particularly sensitive to power attributes in a proposal. Therefore, we posit:

> *Hypothesis 2. The relationship between the number of power cues in a proposal and its evaluation is more positive for entrepreneurs than for managers or investors.*

Managerial role

Several organizational studies on new ventures highlight the difference between successfully starting a new firm (entrepreneurship) and successfully managing an existing one (Boeker and Karichalil, 2002). This study follows the definition proposed by Busenitz and Barney (1997): "managers are individuals with middle to upper-level responsibilities with substantial oversight in large organizations." Other studies compare managers' personal traits with those of entrepreneurs (Stewart and Roth, 2001; Apospori et al., 2005; Tan, 2001), but few compare either of these actors with investors. Many studies highlight the fact that entrepreneurs are often primarily interested in setting up a new venture in order to market their invention. However, beyond that, they may not have the managerial interest or capability required for an established firm (Willard et al., 1992), where they may have to focus on general management tasks or follow predefined procedures. Moreover, in an established company, people can draw on more resources than in a new venture, which is why managers embedded in larger organizations have been described as being more risk-averse than entrepreneurs (Tan, 2001; Amihud and Lev, 1981; Stewart and Roth, 2001).

In a comparative study of 324 business owners and a sample of 342 managers, Stewart et al. (1999) noted that managers had lower risk appetite than entrepreneurs. Nevertheless, these authors acknowledge that entrepreneurs' risk propensity is not always clear-cut, and their results contradict several earlier studies that found no significant differences between entrepreneurs and managers (e.g. Brockhaus, 1980; Low and Macmillan, 1988; Busenitz and Barney, 1997) or the general population (e.g. Brockhaus, 1976; Brockhaus and Nord, 1979). Empirical evidence on the differences in opportunity evaluation between entrepreneurs and managers during the very early stages of new-venture formation is scarce, and this study follows up on the discussion. We add to the debate on attitudes towards risk by examining the relationship between the proportion of risk cues in proposals and the scores allocated by the three types of evaluators. We side with Stewart et al. (1999) and take the position that managers have a higher aversion to risk (similarly Stewart and Roth, 2001; Tan, 2001), and argue that managers dislike business ideas and plans containing more risk cues. Thus:

Hypothesis 3. The relationship between the number of risk cues in a proposal and its rating is more negative for managers than for entrepreneurs and investors.

Investor role

The relationship between VC investors and founding teams is characterized by high levels of information asymmetry. At any stage of the startup life cycle, the fact that an experienced third party (e.g. business angel or VC) has already vetted a particular funding request and deemed it worth investing in is typically regarded as a positive cue (Kirsch et al., 2009). In this context, studies have found that having reputable VC investors on board conveys valuable information to subsequent IPO investors and enhances legitimacy in their eyes (Megginson and Weiss, 1991; Hsu, 2004; Higgins and Gulati, 2003). Similarly, Stuart et al. (1999) found that those startups that had succeeded in attracting prominent strategic alliance partners and prestigious organizational equity investors (i.e. large firms holding well-cited patents and with many strategic alliances) earned higher valuations from IPO investors. More generally, the effects from *affiliations* with prominent ("star") scientists (Wry and Lounsbury, 2013; Higgins et al., 2011), prestigious universities (Wang and Shapira, 2009; Rindova et al., 2005), and corporations as alliance partners or equity investors have been intensively studied (Hsu and Ziedonis, 2008). Building on these insights, we argue that investors have a strong preference for affiliation cues in business-opportunity proposals, and we thus hypothesize:

Hypothesis 4a. The relationship between the number of affiliation cues in a proposal and its rating is more positive for investors than for entrepreneurs and managers.

Besides a venture's ability to attract prominent third-party affiliates, there is a range of other *achievements* that affect perceptions of a new venture's quality, such as successfully obtaining a patent (cf. Haeussler et al., 2014; Hsu and Ziedonis, 2008). According to Shane (2005, p. 102) extant empirical research suggests that firm founders who have a greater need for achievement appear to have faster-growing ventures than those with lesser needs.

From an external evaluator's perspective, the presentation of previous achievements, as well as the definition of targeted future milestones, is one of the key elements of a proposal. Due to the limited availability of performance data at the very early stages of a new venture, investors have a strong focus on verifiable achievements (Kirsch et al., 2009; Chen et al., 2009). We thus hypothesize that individuals with an investment occupation have a stronger affinity with proposals that emphasize achievements.

Hypothesis 4b. The relationship between the number of achievement cues in a business idea/plan proposal and its rating is more positive for investors than for entrepreneurs and managers.

By nature, investors seek opportunities that promise high rewards, typically in terms of financial returns (Rea, 1989, p. 395; DeGennaro, 2012; Rind, 1981; Manigart et al., 2002), but sometimes in other respects — for instance, regarding positive social benefits in the case of non-profit donors. In general, most investors do not select business opportunities purely on the basis of financial reward, and different types of investors place differing emphasis on financial return (Knockaert et al., 2010; Mason and Stark, 2004). Nevertheless, investors are precisely characterized by their motivation to provide funding on the promise of some kind of reward, whether it be financial return, technological progress, local job creation, benefit to society, etc. Hence, we hypothesize that investors have a particular affinity with proposals containing more cues related to rewards.

Hypothesis 4c. The relationship between the number of rewards cues in a proposal and its rating is more positive for investors than for entrepreneurs and managers.

4. Data and method

4.1. Empirical setting

This study uses archival data from a nationwide Swiss startup competition in which one of the authors was involved as an organizer in 2015. During the examined period (2004–2014), the contest was held every two years, with the goal of fostering Swiss entrepreneurship in general, and high-tech entrepreneurship in particular. The competition was a joint initiative of two large technology universities, two governmental institutions, and two private companies — supported by several major Swiss companies who act as financial sponsors and business network providers. Participation was open to any individual or team with an idea/plan for a new venture in any industrial sector. Two prerequisites for taking part were (a) that at least one team member must be domiciled in Switzerland or the Principality of Liechtenstein, and (b) that the new venture, if already founded, must have been officially incorporated within the previous two years.

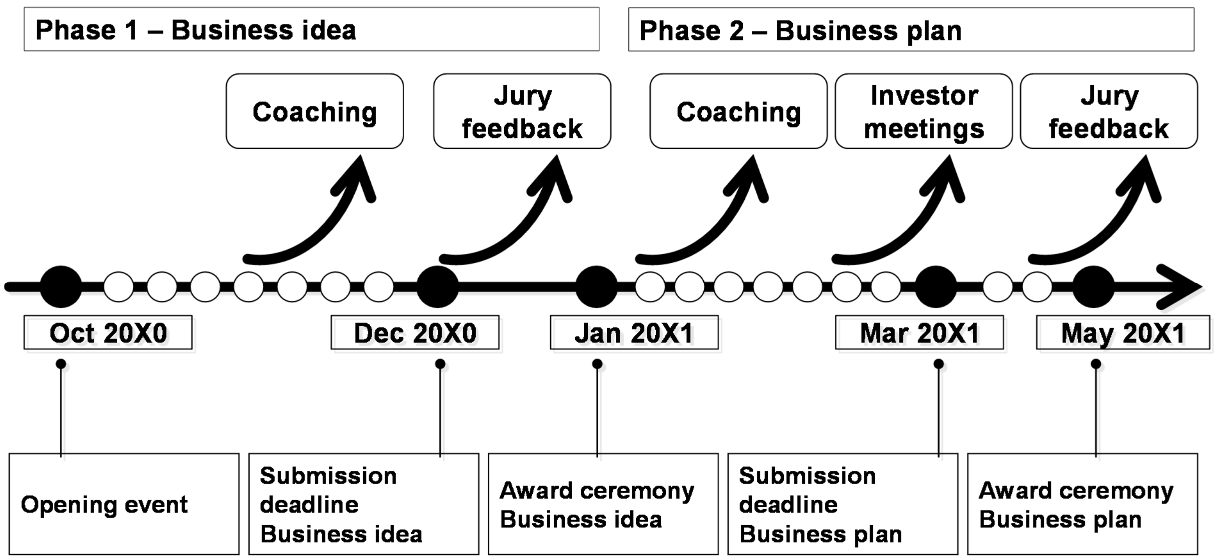

Figure 1: Exemplary sequence of the competition.

Each edition of the competition comprised *two sequential streams* (**Figure 1**): a business-idea contest and a business-plan contest. In the business-idea stream, startup teams had to submit a concise (six pages maximum) and compelling document in the form of an executive summary, primarily focusing on customer benefits and potential markets. This format aimed to encourage people to consider entrepreneurship and provide guidance during the earliest exploration. In the business-plan stream, teams submitted a more detailed (20–30-page) analysis of the business opportunity, including sections on financing, opportunities, and risks; the management team; market and competition analysis; and an implementation plan. Teams were given general guidelines on structuring their proposals. The streams were sequential; startup teams could enter either or both. We investigate the two streams separately.

Phase 1: Preparation of a compelling business idea/plan document

Contest participants were supported through optional activities (seminars, individual coaching, networking events), but above all through the assessment and feedback by the jurors. Over the three months preceding the submission date, teams could choose from seminars on topics such as early-stage financing, marketing, and intellectual property rights (IPR), plus a voluntary individual coaching program offering advice from industry experts from diverse sectoral and functional roles. The aim was to give teams the skills they needed to develop a sound entrepreneurial concept and capture it in documentary form.

Phase 2: Juror process

Submitted documents entered a staged evaluation process in which a number of domain experts assessed them. To enable participants to understand judgment decisions and obtain constructive feedback, jurors were encouraged to add brief comments on their rating for each question in the evaluation form (see below). Typically, a total number of four jurors were assigned to each project. To enhance objective evaluations and fairness, in the allocation the organizers aim to avoid personal relationships between the projects and the juror (i.e. juror should not have been a coach to a team to be evaluated). In turn, the general terms and conditions also require a juror to refrain from an evaluation of a specific project in case of a possible conflict-of-interest – regardless of a relationship within or outside the competition context.

Each juror rates the respective project independently, using an online portal. As in similar competitions (e.g. Foo et al., 2005), the organizers invited many professional experts to take part, so each one only evaluated a few documents and could devote more attention to each one. The competition's board of directors appointed the jurors based on their professional profile: they were flagged as either "entrepreneur" or "venture capitalist". The former *category of jurors* was mainly composed of entrepreneurs but also included company managers and consultants; the VC group comprised individuals with a professional role in venture capital or private equity, or representatives from institutions offering other sources of startup financing, such as convertible loans offered from banks specifically to startup companies.

Jurors used four different *evaluation forms*, each including different sets of questions and weightings depending on the competition stream (business idea vs. business plan) and the juror's classification ("entrepreneur" or "VC"). The four forms remained unchanged throughout the examination period (2004–2014) (**Tables 2a, 2b**).

Table 2a: Evaluation questionnaire for business idea projects.

Nr.	Topic Area	Criteria	Weight
*Juror types: Entrepreneurs and managers**			
1	Customer benefit	Differentiated vis-à-vis comparable products	12.5%
2		Provides a solution to a customers' need	12.5%
3	Market and competition	Sustainable competitive advantage	12.5%
4		Sales potential	12.5%
5	Revenue mechanism	Realistic estimate of costs and price, attractive margins	25.0%
6	Overall impression	Subjective impression 1) Mandatory entry: overall impression, clear formulation/presentations, consistent figures. 2) If available (does not count towards the evaluation): impression of the team (competencies, composition, etc.)	25.0%
Juror type: Investor			
7	Business potential	Sound business concept, attractive product	25.0%
8		Market is attractive	25.0%
9	Financing potential	Subjective impression 1) Mandatory entry: attractiveness of investment (appropriate returns). 2) If available (does not count towards the evaluation): impression of the team (competencies, composition, etc.)	50.0%

* The organizers of the competition only distinguished between investors and non-investors (labelled as “entrepreneurs”). We decomposed the organizer’s juror category “entrepreneur” into effective entrepreneurs (those who had actually co-founded a new firm) and managers.

Table 2b: Evaluation questionnaire for business plan projects.

Nr.	Topic Area	Criteria	Weight
*Juror types: Entrepreneurs and managers**			
10	Executive Summary	Completeness, attractiveness, conciseness	10.0%
11	Product idea	Customer need, target customer identification, product differentiation	10.0%
12	Management team	Competencies, composition	10.0%
13	Marketing	Market analysis, market segmentation, marketing strategy	10.0%
14	Business system/organization	Effectiveness, appropriateness, partnerships	10.0%
15	Implementation plan	Development steps, critical path	10.0%
16	Risks	Risk identification, risk assessment, countermeasures	10.0%
17	Financing	Revenue mechanisms, costs/margins, liquidity planning, capital requirements	10.0%
18	Overall impression	Consciseness, consistency, presentation	20.0%
Juror type: Investor			
19	Business potential	Market attractiveness, product potential, business concept, growth potential	25.0%
20	Management team	Competencies, composition	25.0%
21	Risks	Risk identification, risk assessment, countermeasures	25.0%
22	Financing potential	Investment attractiveness, returns, quality of deal proposals	25.0%

* The organizers of the competition only distinguished between investors and non-investors (labelled as “entrepreneurs”). We decomposed the organizer’s juror category “entrepreneur” into effective entrepreneurs (those who had actually co-founded a new firm) and managers.

The scoring scale for each individual question in **Tables 2a and 2b** ranged from 0 (worst) to 9 (best) and aimed to reflect how well each evaluation criterion had been fulfilled. The project’s *overall score* *O* was calculated by

$$O = \frac{1}{N}\sum_{n=1}^{N}\left(\sum_{q=1}^{Q}\frac{s_{qn}}{9}\cdot w_q\cdot 100\right)$$

where s_{qn} is the score point that juror n = 1,…, N awards to question q = 1,…, Q; w_q is the weighting factor of question q in percent, based on the importance of the question (see weighing factors in **Tables**

2a & 2b). The term in brackets delivers the total score that an individual juror awards to a project and the first sum operator serves to calculate the arithmetic average across all the jurors n = 1,…, N assigned to a project. As final result, a project's overall score O could range from 0 (worst) to 100 (best). Each juror's assessment had the same weighting for the overall project score regardless of whether they had been designated "entrepreneur" or "VC."

4.2. Data source

Our primary data source is the startup competition database, which contains business-idea and business-plan documents and metadata at the team and individual level for all six editions of the biennial contest held between 2004 and 2014 inclusive: a total of 693 business-idea and 379 business-plan documents in English[13] (**Tables 3a, 3b**). Our analysis only focuses on jurors' evaluations based on submitted business-idea or business-plan documents in English language. The analyzed dataset does not reflect the results from pitching presentations to a panel of jurors.

Across the two streams of the contest, our results draw on a total of 4198 juror evaluations. As a first step, we split the organizer's juror category "entrepreneur" into effective entrepreneurs (those who had actually co-founded a new firm) and managers. This resulted in 1413 assessments attributable to jurors with an entrepreneurial role, 1266 to those with a managerial role, and 1519 to those with an investor role (**Table 3c**). Between 2004 and 2014, the workload for each juror was about the same, irrespective of his/her professional role. For example, for the business idea track entrepreneurs vetted, on average 8.8 business ideas per contest edition, as compared to 8.7 proposals by managers, and 10.5 business idea proposals evaluated by investors, respectively (**Table 3c**).

[13] For the examination period 2004 to 2014, besides the 1072 proposals in English, another 641 proposals were submitted in German, 118 in French, and six in Italian, respectively.

Table 3a: Number of participating projects (= submitted documents*) by year.

Stream	2004	2006	2008	2010	2012	2014	**Total**
Business Idea	77	72	106	133	129	176	**693**
Business Plan	0	37	56	96	81	109	**379**
Total	**77**	**109**	**162**	**229**	**210**	**285**	**1072**

* Only documents submitted in English language considered in this table and for the further analysis.

Table 3b: Number of project proposals* by industry sector.

Industry	**Business Idea**	**Business Plan**	**Total**
Agriculture/food	16	6	22
Chemicals/materials	16	9	25
Commerce	12	6	18
Construction/property	10	8	18
Consumer Goods	7	4	11
Education	13	3	16
Electronics/Hardware	50	35	85
Energy	27	19	46
Environment	17	9	26
Financial services	22	8	30
Health	31	10	41
Mech. Engineering	15	9	24
Media	22	19	41
Medical technology	57	48	105
Pharma/biotechnology	76	46	122
Services	79	35	114
Software	106	51	157
Sports & Wellness	7	4	11
Telecommunications	23	9	32
Textiles	2		2
Tourism/gastronomy	17	7	24
Transport	10	8	18
Web & Portals	58	26	84
Total	**693**	**379**	**1072**

* Only documents submitted in English language considered in this table and for the further analysis.

Table 3c: Overview of the jurors' engagements.

Dimension	Overall	Entrepreneurs	Managers	Investors
Total number of different jurors active in any contest edition 2004-2014	332	114	118	100
Total number of individual juror assessments 2004-2014[1)], whereof	4198	1413	1266	1519
Business ideas	2757	925	819	1013
Business plans	1441	488	447	506
Average number of assessments by each active juror per contest edition[2), 3)], whereof	11.1	10.7	10.0	12.7
Business ideas	9.3	8.8	8.7	10.5
Business plans	4.1	3.9	3.8	4.5

1) The stated amounts refer to proposals submitted in English language over the six contest editions 2004-2014.

2) To provide an overview of the workload per juror, the stated average amounts are irrespective of the language of the evaluated document and, thus, besides submissions in English, it also includes submissions in German, French, and Italian.

3) Based on the sequential format of the competition (see **Figure 1**) a large number of jurors engaged in both competition streams (business idea and plan) in the same contest edition (year). For that reason the total average number of assessments by one juror (total average line) exceed the average number of assessments on the disaggregated level (when considering the average amounts of the business idea and business plan evaluations in isolation; see the respective subtotal lines).

4.3. Data analysis

Research framework

To address the research question how individuals with different professional roles vary in their evaluation of given business opportunities, the individuals' opportunity templates are central and need to be better understood. The opportunity templates are the nexus between the two observable variables: 1) the information about the venturing project, which are mainly transmitted by linguistic cues (potentially backed by visual illustrations and numbers) as the independent variables; and 2) the score points that the project receives as the dependent variables. Yet, the connection is relatively uncovered and linking these variables enables to deduce insights on the structure of opportunity templates.

Early experiments by Rutherford pertaining to the atomic structure serve as a good analogy (Rutherford, 1911). In the case of this experiment, researchers could deduce an atomic structure based on how an alpha particle beam scattered when it strikes a thin metal (e.g. gold) foil as a target object. The researchers noticed that many alpha particles just passed through the empty space in the atom, whereas others were deflected to the sides. The researchers inferred that the deflection occurs when approaching the nucleus.

The allegory to our research approach contains striking similarities to our investigation of how jurors arrive at different evaluation results, or, more precisely, how the differences in the evaluation results are related to specific cues in the business idea/plan document. In the experiments from the early 20th century the atomic structure was the not yet decrypted link between the beam of alpha particles and their impact point on a detecting screen. In our context it is each individual's opportunity template that is the "black box", which is targeted with certain cues contained in a business idea/plan document and which leads to variations peoples' opportunity evaluation. Along these lines of reasoning, the research framework of this study must be designed to enable to discern those cues that have significant effects on the opportunity evaluation from those that do not have such an impact. In other words and sticking to the language of the atomic scientists, some informational cues may just "fly straight through" the opportunity template without significant deviations, thus without significant impact on the evaluation score. Summarizing these thoughts, our resulting research framework is presented in **Figure 2**.

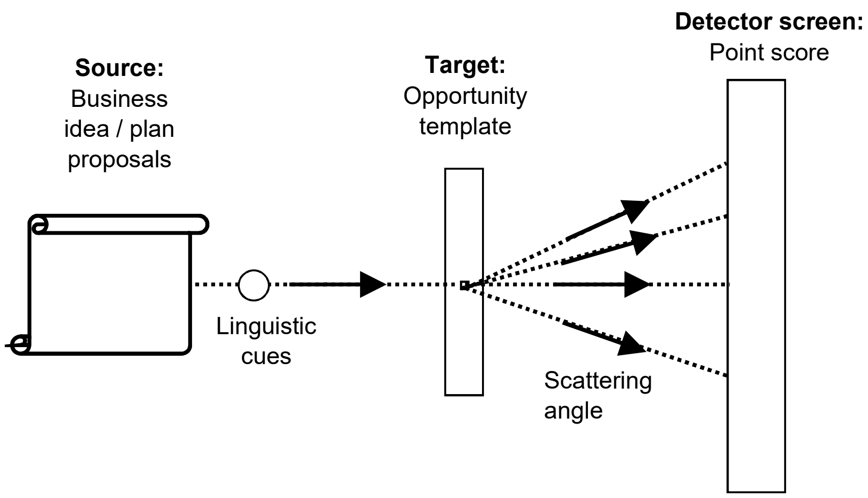

Figure 2: Research framework based on Rutherford's (1911) gold foil experiment.

Dependent variables

We used jurors' ratings of business-idea and business-plan documents as our two dependent variables. Projects' overall scores are decisive in determining the final winners of the competition. On a more disaggregated level, we further distinguished the scoring based on jurors' professional roles. For that purpose, we decomposed the pool of jurors into the three categories: entrepreneurs, managers, and investors.[14] In order to classify individual jurors, we drew on the personal information from the organizers' database and, in the case of uncertainties, additionally on a web search on the individual's professional role. As a result, we can distinguish between the scores allocated by all three types of jurors overall and, more specifically, the scores given by each juror type (entrepreneurs, managers, and investors), for both dependent variables.

[14] As mentioned above, the organizers of the competition do not distinguish between entrepreneurs and managers, and these two types of jurors use the same evaluation questionnaire.

Independent variables

Regarding independent variables, we build on the methods used by Foo et al. (2005) in their analysis of business-idea proposals submitted to a venture competition in Singapore. We relied on the documents submitted by the team to analyze our independent variables of interest.

Study variables

To analyze the large number of documents submitted to the competition for certain cues in the text body, we utilized the well-established psycholinguistic software tool "Linguistic Inquiry and Word Count" (LIWC) (Tausczik and Pennebaker, 2010; Pennebaker et al., 2015). Based on an internal dictionary, LIWC scans text files for the occurrence of words that relate to predefined psychology-relevant categories (e.g. risk or reward cues). It calculates the prevalence of word categories expressed as a percentage, controlling for the length of the text (Riordan and Kreuz, 2010; Crilly et al., 2015). Analyzing the words people use, and in what frequency and context, provides information that can be used to gauge their psychological states and processes, and various aspects of their personality (Konnikova, 2015; Nadkarni and Chen, 2014). Linguistic analysis is increasingly used in entrepreneurship (e.g. Wolfe and Shepherd, 2015; Moss et al., 2015) as well as general management (e.g. Nadkarni and Chen, 2014; Pfarrer et al., 2010; Crilly et al., 2015) research.

The focus of this study is the extent to which differences in evaluations are related to cues associated with the following attributes: affiliation, achievements, power, reward, and risk (see **Table 1** for exemplary words from the LIWC dictionary). In the LIWC categorization, these five dimensions together make up the main category "drives". These drives have been shown to be very precisely captured through linguistic analysis, and have been used in political psychology (Winter, 2011; 2005; Hogenraad, 2005). We are interested in understanding how evaluators score business plans based on linguistic cues that reflect these drives.

The LIWC dictionary for this category comprises a total of 1103 words. The LIWC built-in dictionaries have been subject to extensive investigations to ensure both the internal reliability and external validity of the results (Pennebaker et al., 2015), and have been considered useful for management research (Brett et al., 2007; Crilly et al., 2015).

Controls

Proposal document length: LIWC returns the results in the form of a percentage of the overall document text, so the study variables do take account of document length. Nevertheless, we add the document length (*word count, "WC"*) as an independent variable to exclude omitted variable biases and control for changes in the jurors' evaluation behavior related to the comprehensiveness of the proposal document.

Furthermore, the organizers of the competition collected several team-specific variables that serve as controls.

Team size. Studies have suggested that team size influences intra-team processes (Foo et al., 2006), and therefore controlling for team-size effects is very common in entrepreneurial research (e.g. Delmar and Shane, 2003; Gruber, 2007). The number of team members in both streams of the contest ranged from 1 to 9. However, during the whole examination period there was only one team in each track that consisted of 9 individuals, and the frequency distribution of team size was left-skewed for both business-idea (mean=1.99; S.D.=1.22) and business-plan (mean = 2.18; S.D.= 1.25) projects.

Diversity of age. The coefficient of variation served as a measure of the diversity of age. Each team's standard deviation of the age of individual team members was divided by the team's mean age, measured in years.

Diversity of gender. Gender diversity was measured utilizing the Herfindal–Hirschman index. The index is frequently used in research on management teams as a measure of heterogeneity across categorical variables (e.g. Hambrick et al., 1996; Talke et al., 2010). The index was calculated by

$$H = 1 - \sum_{j=1}^{J} p_j^2$$

where p_i represented the fraction of women in each project, and j = 1, …, J are the venture projects.

Diversity of employment status. The participants had to report whether they were students, employees, or self-employed. The calculation of the Herfindal–Hirschman index enabled the determination of the diversity level.

Industry controls. In line with Foo et al. (2005), we controlled for the industry sector, since they are characterized by varying degrees of barriers to entry and competitive rivalry. As part of their metadata reporting, teams had to select the industry closest to their planned venture from a list.

Patents. Extant literature has found that information on the protection of the intellectual property underlying a new technology is particularly important to external evaluators when vetting a business opportunity (e.g. Knockaert et al., 2010; Kaplan et al., 2009). To control for effects arising from the discussion or omission of patent-related considerations in the document, we controlled for the occurrence of the term "patents" – operationalized by manually specifying an additional category in the text analysis software LIWC. In general, a conclusion on whether a technology is actually patentable or not is only possible after extensive technical and legal due diligence by a domain expert – a skill that some of the jurors may possess. But like for the studied linguistic cue variables (affiliation, achievements, power, reward, and risk), for the purposes of this study we do not scrutinize the validity of the assertions in the document on patents/patentability nor gauge whether these cues occur in context with the own technology/firm or in context with a competitor. In some cases the patentability may even be negated in the text. However, it seems reasonable to include the patent related variable to control for effects that may arise from the fact that, and the extent to which, patent related issues are considered in some documents, whereas in other opportunity documents patent considerations are just omitted at all.

5. Results

5.1. Descriptive statistics

Tables 4a and 4b present the descriptive statistics and correlations for the variables on business-idea and business-plan proposals respectively. Considering the mean values of the five study variables together (affiliation, achievements, power, reward, and risk), in the business-idea documents these five cue variables cover about 9.19% of the total text length of 1652.54 words, thus 151.87 words per document that constitute the basis for the analysis. Similarly, for business plans the five cue categories account for 8.83% of the total text length of 9563.40 words, resulting in a total number of 844.45 words per document as the data base for the analysis. To put these amounts into perspective, the LIWC analysis reports on our dataset reveal that the five focal variables have, in comparison to other linguistic categories pre-specified in the LIWC software, a high text coverage rate - aside from functional word categories (e.g. articles, prepositions, conjunctions). Thus, if taking the coverage rate as an indicator for the suitability of the chosen linguistic variables for a statistical analysis, the main category "drives" with its relatively high text coverage rate provides a robust basis for our research.

Over all types of jurors, the project scores of the 693 business-idea proposals ranged from 2.78 points (minimum) to 90.97 points (maximum) (mean = 51.00; S.D. = 16.07). For the 379 business plans, the distribution was narrower: project scores ranged from 10.28 to 88.15 points (mean = 60.04; S.D. = 16.34). Concerning these differences, it is important to remember that different evaluation questionnaires were used for business ideas and business plans respectively. Together, the deviations in the score distribution and the different questionnaires require a differentiated analysis for both streams, which is presented below.

Table 4a: Descriptive statistics and correlations for business ideas.

		Mean	SD	N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Total_Points_overall	51.00	16.07	693	1.00															
2	Entrepreneur_Points	51.64	18.93	554	.78**	1.00														
3	Manager_Points	51.49	20.53	518	.76**	.31**	1.00													
4	Investor_Points	50.66	19.99	630	.79**	.42**	.35**	1.00												
5	affiliation	2.14	1.50	693	.00	-.01	-.01	.05	1.00											
6	achieve	2.61	1.06	693	-.02	-.01	.00	-.03	.22**	1.00										
7	power	2.77	1.05	693	.07	.10*	.07	.04	.09*	.42**	1.00									
8	reward	1.15	.57	693	-.15**	-.10*	-.10*	-.15**	.18**	.46**	.15**	1.00								
9	risk	.52	.49	693	.02	.03	-.01	.04	-.11**	.05	.16**	-.01	1.00							
10	patent	.09	.19	693	.13**	.13**	.09*	.07	-.14**	.03	.01	-.05	.10**	1.00						
11	WordCount (WC)	1652.54	963.60	693	.31**	.28**	.22**	.21**	.06	-.08*	.07	-.03	-.02	.00	1.00					
12	No. Teammembers	1.99	1.22	693	.18**	.15**	.11*	.15**	.12**	.06	.05	-.03	.04	-.01	.11**	1.00				
13	Coeff_Variation_Age	.15	.14	691	.01	.03	-.01	.04	.18**	.01	.05	.13**	-.03	-.04	.07	.06	1.00			
14	Herfindahl_Gender	.08	.17	693	.05	.06	.02	.01	.04	-.03	.02	-.04	-.03	-.02	.07	.31**	.04	1.00		
15	Herfindahl_Status	.12	.21	693	.11**	.08*	.11*	.07	.06	.00	.03	.05	.01	-.06	.10*	.48**	.04	.25**	1.00	
16	Total No. of evaluations	3.98	.87	693	.04	.02	.03	-.06	-.04	-.05	-.01	-.06	.02	.02	.13**	.05	-.15**	.06	.08*	1.00

** Correlation is significant at the .01 level (2-tailed).

* Correlation is significant at the .05 level (2-tailed).

Table 4b: Descriptive statistics and correlations for business plans.

		Mean	SD	N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Total_Points_overall	60.04	16.34	379	1.00															
2	Entrepreneur_Points	61.85	18.96	305	.81**	1.00														
3	Manager_Points	62.42	21.21	286	.84**	.42**	1.00													
4	Investor_Points	58.02	18.75	352	.77**	.42**	.39**	1.00												
5	affiliation	1.93	1.15	379	-.04	-.07	-.06	-.08	1.00											
6	achieve	2.58	.78	379	.03	.02	.00	.00	.37**	1.00										
7	power	2.77	.78	379	.05	.10	.00	.05	.23**	.51**	1.00									
8	reward	1.00	.36	379	-.17**	-.11*	-.13*	-.16**	.36**	.53**	.37**	1.00								
9	risk	.55	.36	379	.00	.04	.02	-.07	-.01	.16**	.25**	.08	1.00							
10	patent	.07	.08	379	.14**	.03	.19**	.15**	-.17**	.05	.03	-.19**	.21**	1.00						
11	WordCount (WC)	9563.40	5892.67	379	.29**	.28**	.22**	.21**	-.18**	-.29**	-.20**	-.24**	-.08	-.04	1.00					
12	No. Teammembers	2.18	1.25	379	.14**	.17**	.11	.00	.09	.00	.05	-.07	.08	.03	.14**	1.00				
13	Coeff_Variation_Age	.15	.11	379	-.17**	-.08	-.12*	-.18**	.05	.01	-.01	.14**	.02	-.06	-.05	-.02	1.00			
14	Herfindahl_Gender	.09	.18	379	.03	.00	.04	.03	.07	-.02	.06	.00	.05	.02	.05	.33**	.01	1.00		
15	Herfindahl_Status	.14	.22	379	-.03	.04	-.03	-.14**	.06	-.10	-.10*	-.01	.02	.02	.07	.45**	.06	.24**	1.00	
16	Total No. of evaluations	3.80	.75	379	.49**	.35**	.44**	.31**	-.02	-.04	-.01	-.15**	-.04	.05	.14**	.12*	-.21**	.00	.08	1.00

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

5.2. Regression results

For the examination period, 2004–2014, the business opportunities captured in the dataset can be assumed to be independent of projects in other years (in terms of the independent variables). Thus, we decided to pool the observations across time. As this may lead to non-identically distributed observations, it necessitates the inclusion of year dummies to allow for changes in the intercept term over time. For example, the intercept for 2014 is the intercept + the coefficient for the dummy 'y2014'. Thus, we include the year dummies in order to allow for changes in the intercept over time (**Tables 5a and 5b**).

Table 5a: OLS regressions predicting the total score points on business idea submissions awarded by the jurors with different professional roles.

	Overall		Entrepreneurs		Manager		Investor	
	Only controls	Full model	Only controls	Full model	Only controls	Full model	Only controls	Full model
affiliation		0.137 (0.407)		0.190 (0.573)		-0.026 (0.636)		0.670 (0.559)
achieve		-0.247 (0.665)		-0.340 (0.998)		0.296 (1.031)		-0.254 (0.914)
power		1.506** (0.606)		2.191** (0.919)		1.108 (0.918)		1.097 (0.819)
reward		-3.490*** (1.144)		-2.955* (1.672)		-3.202* (1.740)		-5.110*** (1.552)
risk		-0.654 (1.164)		-0.119 (1.684)		-1.696 (1.729)		0.723 (1.596)
WordCount (WC)	-0.004*** (0.001)	-0.004*** (0.001)	-0.004* (0.002)	-0.003* (0.002)	-0.005** (0.002)	-0.005** (0.002)	-0.003* (0.002)	-0.003 (0.002)
Number_Teammembers	1.527*** (0.541)	1.398** (0.543)	1.694** (0.761)	1.606** (0.762)	1.313 (0.812)	1.245 (0.825)	1.809** (0.729)	1.525** (0.730)
Coeff_Variation_Age	-6.225 (4.546)	-5.172 (4.582)	-4.870 (6.475)	-4.071 (6.547)	-0.383 (7.125)	0.564 (7.219)	-5.904 (6.424)	-4.252 (6.455)
Herfindahl_Gender	-0.373 (3.409)	-1.178 (3.389)	-1.281 (4.712)	-1.960 (4.709)	0.169 (5.195)	-0.365 (5.200)	-3.156 (4.533)	-3.991 (4.502)
Herfindahl_Status	4.362 (3.147)	5.249* (3.137)	2.665 (4.379)	3.061 (4.383)	6.560 (4.770)	7.167 (4.787)	2.260 (4.295)	3.721 (4.282)
Nr. of_evaluations_overall	4.535*** (0.915)	4.603*** (0.909)	3.277** (1.432)	3.396** (1.429)	3.469** (1.441)	3.651** (1.449)	2.785** (1.363)	2.710** (1.356)
Chemicals_Materials	7.828 (5.153)	7.199 (5.114)	5.452 (7.513)	4.294 (7.501)	0.844 (7.144)	0.305 (7.155)	18.405** (7.204)	16.802** (7.161)
Commerce	0.555 (5.532)	2.464 (5.549)	-1.815 (7.914)	-0.427 (7.978)	-4.606 (7.646)	-2.564 (7.777)	13.323 (8.304)	16.627** (8.364)
Construction_Property	3.572 (5.876)	2.611 (5.834)	7.703 (8.609)	5.963 (8.604)	-6.663 (8.319)	-7.132 (8.340)	14.256* (8.600)	12.417 (8.547)
ConsumerGoods	15.991** (6.581)	16.136** (6.531)			16.868* (8.639)	17.062** (8.645)	16.713* (8.965)	16.457* (8.889)
Education	-4.444 (5.448)	-5.729 (5.434)	-3.689 (9.601)	-4.428 (9.658)	-15.660** (7.324)	-16.623** (7.395)	8.214 (7.596)	6.598 (7.579)
Electronics_Hardware	8.937** (4.203)	8.114* (4.179)	2.664 (5.806)	1.283 (5.808)	9.044 (5.730)	8.277 (5.759)	16.072*** (6.203)	14.954** (6.180)
Energy	9.820** (4.577)	7.730* (4.593)	2.531 (6.590)	0.159 (6.636)	17.325*** (6.151)	15.440** (6.250)	10.723 (6.532)	8.202 (6.568)
Environment	3.636 (5.034)	3.651 (5.004)	2.516 (6.972)	2.761 (6.961)	-10.486 (8.280)	-10.532 (8.342)	8.085 (7.279)	7.528 (7.241)
FinancialServices	7.702 (4.766)	7.775 (4.777)	3.436 (7.015)	1.994 (7.127)	11.416* (6.386)	11.867* (6.483)	11.451* (6.799)	11.020 (6.839)
Health	3.287 (4.481)	3.667 (4.470)	-4.434 (6.095)	-4.695 (6.103)	1.948 (6.372)	2.737 (6.422)	14.638** (6.682)	14.054** (6.673)
Media	7.144 (4.770)	8.179* (4.740)	2.964 (6.513)	3.902 (6.507)	9.977 (6.959)	10.538 (6.982)	12.881* (6.788)	13.915** (6.730)
MechEngineering	6.413 (5.220)	6.356 (5.186)	-2.362 (7.285)	-2.633 (7.271)	8.967 (7.440)	8.650 (7.464)	16.132** (7.859)	15.669** (7.813)
MedicalTechnology	13.495*** (4.124)	13.237*** (4.099)	9.209 (5.917)	8.678 (5.917)	12.147** (5.549)	11.924** (5.572)	20.654*** (6.027)	19.815*** (6.000)
Pharma_Biotechnology	14.506*** (4.012)	13.980*** (3.989)	10.039* (5.536)	8.920 (5.537)	7.119 (5.726)	6.551 (5.753)	24.923*** (5.874)	23.783*** (5.856)
Services	2.958 (3.995)	2.759 (3.984)	0.459 (5.530)	-0.405 (5.552)	-0.211 (5.328)	-0.492 (5.357)	13.628** (5.928)	13.106** (5.917)
Software	5.307 (3.897)	5.428 (3.893)	-2.947 (5.388)	-3.309 (5.414)	6.870 (5.275)	6.800 (5.324)	14.241** (5.765)	13.788** (5.767)
Sports_Wellness	13.150** (6.605)	13.029** (6.561)	-5.123 (9.035)	-5.614 (9.032)	12.203 (9.170)	12.769 (9.182)	29.231*** (8.974)	27.936*** (8.932)
Telecommunications	2.239 (4.729)	2.782 (4.704)	5.682 (6.581)	5.571 (6.580)	-0.601 (6.420)	-0.042 (6.452)	6.181 (6.750)	6.007 (6.723)
Textiles	2.844 (10.908)	2.201 (10.825)	8.282 (19.017)	6.454 (18.986)	4.153 (14.331)	4.410 (14.345)	6.729 (14.418)	4.782 (14.311)
Tourism_Gastronomy	4.578 (5.039)	5.181 (5.017)	-8.866 (7.871)	-9.965 (7.898)	6.450 (6.947)	6.752 (6.982)	15.106** (7.270)	15.979** (7.230)
Transport	-0.231 (5.845)	0.508 (5.816)	-2.046 (7.928)	-1.979 (7.950)	-2.644 (9.092)	-2.738 (9.142)	3.210 (8.049)	3.584 (8.013)
Web_Portals	1.034 (4.139)	2.328 (4.129)	-5.488 (5.789)	-5.261 (5.805)	-5.555 (5.594)	-4.762 (5.638)	11.532* (6.060)	12.490** (6.041)
Patent	3.926 (3.083)	4.498 (3.084)	6.169 (4.084)	6.599 (4.124)	4.674 (4.338)	5.203 (4.366)	1.392 (4.100)	2.068 (4.101)
y2006	-0.874 (2.542)	-1.031 (2.528)	-4.058 (3.612)	-4.429 (3.624)	1.365 (4.056)	1.011 (4.062)	2.538 (3.337)	2.570 (3.322)
y2008	0.357 (2.269)	0.413 (2.261)	2.818 (3.233)	2.477 (3.255)	-9.066** (3.603)	-8.816** (3.627)	5.212* (3.043)	5.468* (3.034)
y2010	4.568** (2.276)	4.371* (2.266)	5.235* (3.160)	4.640 (3.167)	-0.737 (3.544)	-0.855 (3.565)	5.116* (3.090)	4.846 (3.074)
y2012	9.462*** (2.310)	9.510*** (2.325)	9.020*** (3.297)	8.819*** (3.333)	4.426 (3.690)	4.666 (3.751)	12.855*** (3.045)	12.465*** (3.060)
y2014	15.604*** (2.395)	15.612*** (2.404)	12.790*** (3.481)	12.512*** (3.509)	10.554*** (3.748)	10.624*** (3.819)	17.212*** (3.210)	17.142*** (3.219)
Constant	20.048*** (5.613)	20.312*** (5.758)	30.300*** (8.299)	28.519*** (8.478)	30.591*** (8.219)	30.592*** (8.520)	15.317* (8.349)	18.014** (8.573)

Observations	691	691	552	552	518	518	628	628
R^2	0.235	0.255	0.148	0.163	0.212	0.221	0.172	0.195
Adjusted R^2	0.196	0.210	0.094	0.101	0.156	0.157	0.125	0.141
Residual Std. Error	14.410 (df = 656)	14.281 (df = 651)	18.040 (df = 518)	17.970 (df = 513)	18.859 (df = 483)	18.845 (df = 478)	18.693 (df = 593)	18.515 (df = 588)
F Statistic	5.942*** (df = 34; 656)	5.707*** (df = 39; 651)	2.725*** (df = 33; 518)	2.623*** (df = 38; 513)	3.812*** (df = 34; 483)	3.476*** (df = 39; 478)	3.632*** (df = 34; 593)	3.648*** (df = 39; 588)
Note:								*p<0.1; **p<0.05; ***p<0.01

Table 5b: OLS regressions predicting the total score points on business plan submissions awarded by the jurors with different professional roles.

	Overall		Entrepreneurs		Manager		Investor	
	Only controls	Full model	Only controls	Full model	Only controls	Full model	Only controls	Full model
affiliation		-0.220 (0.750)		-0.526 (1.107)		-0.499 (1.195)		-0.852 (0.973)
achieve		0.606 (1.248)		0.376 (1.933)		-1.041 (1.867)		0.409 (1.616)
power		1.716 (1.137)		3.484** (1.663)		0.402 (1.768)		2.120 (1.469)
reward		-3.968 (2.577)		-5.556 (3.865)		2.609 (4.328)		-3.106 (3.324)
risk		-0.964 (2.136)		1.772 (3.083)		2.413 (3.270)		-4.724* (2.687)
WordCount (WC)	-0.002 (0.001)	-0.002 (0.001)	-0.002 (0.002)	-0.002 (0.002)	-0.003 (0.002)	-0.003 (0.002)	-0.0002 (0.002)	-0.0001 (0.002)
Number_Teammembers	1.646** (0.680)	1.498** (0.692)	2.263** (1.020)	1.871* (1.035)	1.045 (1.048)	1.124 (1.075)	0.725 (0.880)	0.720 (0.891)
Coeff_Variation_Age	-8.587 (6.584)	-7.513 (6.639)	-0.381 (9.697)	0.528 (9.718)	-9.761 (10.637)	-11.210 (10.864)	-14.143* (8.516)	-13.248 (8.605)
Herfindahl_Gender	0.541 (4.162)	0.378 (4.189)	-5.243 (6.278)	-6.562 (6.304)	4.213 (6.229)	3.834 (6.316)	3.065 (5.264)	3.153 (5.282)
Herfindahl_Status	-6.715* (3.771)	-5.283 (3.855)	0.736 (5.521)	3.989 (5.646)	-4.859 (5.751)	-5.403 (5.890)	-13.661*** (4.756)	-11.939** (4.863)
Nr. of_evaluations_overall	11.279*** (1.038)	11.080*** (1.048)	10.244*** (1.640)	9.979*** (1.649)	14.415*** (1.635)	14.688*** (1.671)	8.959*** (1.531)	8.742*** (1.545)
Chemicals_Materials	8.674 (7.234)	8.290 (7.260)	2.595 (12.133)	1.605 (12.107)	2.626 (9.813)	2.862 (9.939)	11.735 (9.506)	11.499 (9.520)
Commerce	0.961 (7.883)	1.532 (7.907)	-4.724 (11.391)	-4.330 (11.380)	-9.565 (11.086)	-10.544 (11.224)	10.464 (10.300)	11.435 (10.311)
Construction_Property	13.131* (7.468)	13.323* (7.494)	4.992 (10.568)	5.131 (10.562)	23.127** (10.268)	22.255** (10.386)	5.731 (10.097)	6.398 (10.105)
ConsumerGoods	6.816 (8.876)	6.814 (8.930)			10.247 (11.787)	10.311 (11.965)	0.166 (11.445)	0.494 (11.480)
Education	2.489 (9.572)	3.027 (9.688)	-12.170 (19.816)	-13.273 (19.982)	5.506 (14.637)	5.904 (14.887)	8.029 (12.282)	8.668 (12.414)
Electronics_Hardware	7.344 (6.130)	7.584 (6.150)	1.661 (8.876)	2.204 (8.876)	18.037** (8.367)	17.702** (8.468)	1.027 (8.232)	1.506 (8.231)
Energy	3.431 (6.405)	3.144 (6.423)	-5.109 (9.346)	-5.538 (9.331)	16.103* (8.696)	15.930* (8.789)	-3.514 (8.657)	-3.637 (8.667)
Environment	4.299 (7.154)	6.000 (7.241)	6.225 (10.284)	10.014 (10.422)	9.432 (12.658)	9.047 (12.818)	-10.015 (9.675)	-7.382 (9.786)
FinancialServices	-4.480 (7.403)	-3.855 (7.541)	-2.884 (11.600)	-4.422 (11.812)	2.612 (9.825)	0.514 (10.117)	-11.755 (9.968)	-9.903 (10.090)
Health	-0.750 (7.037)	0.181 (7.091)	1.754 (10.102)	2.541 (10.163)	9.882 (10.014)	9.419 (10.297)	-16.669* (9.443)	-14.636 (9.496)
Media	6.350 (6.404)	7.304 (6.435)	2.728 (9.216)	4.487 (9.234)	8.459 (9.234)	8.053 (9.348)	4.307 (8.584)	5.460 (8.602)
MechEngineering	2.397 (7.216)	3.103 (7.279)	2.165 (10.336)	2.520 (10.396)	6.602 (9.763)	5.997 (9.912)	-4.300 (9.685)	-2.236 (9.734)
MedicalTechnology	9.263 (5.963)	9.617 (5.984)	6.417 (8.736)	6.850 (8.742)	9.672 (8.002)	8.998 (8.092)	6.321 (8.017)	6.940 (8.029)
Pharma_Biotechnology	8.451 (5.973)	8.718 (6.009)	3.707 (8.677)	3.852 (8.694)	10.345 (8.200)	9.279 (8.343)	6.997 (8.028)	7.859 (8.050)
Services	0.771 (6.096)	1.357 (6.129)	1.544 (9.002)	2.442 (9.008)	1.439 (8.308)	0.501 (8.433)	-5.309 (8.326)	-4.379 (8.357)
Software	7.526 (5.932)	8.484 (6.026)	2.398 (8.637)	3.384 (8.764)	10.925 (8.058)	10.130 (8.279)	3.839 (8.022)	6.324 (8.109)
Sports_Wellness	-2.313 (8.808)	-1.501 (8.871)	-4.515 (13.291)	-3.473 (13.290)	-2.022 (11.668)	-2.163 (11.894)	4.091 (11.330)	5.884 (11.380)
Telecommunications	7.507 (7.236)	9.055 (7.416)	-2.905 (11.216)	-0.756 (11.544)	13.650 (9.797)	14.356 (10.151)	4.544 (9.512)	8.130 (9.706)
Textiles								
Tourism_Gastronomy	2.575 (7.621)	3.140 (7.677)	1.330 (12.317)	2.625 (12.345)	6.430 (10.505)	6.155 (10.647)	-7.102 (10.336)	-5.654 (10.367)
Transport	7.664 (7.409)	8.883 (7.473)	2.479 (11.046)	4.000 (11.094)	9.693 (10.114)	8.652 (10.277)	7.239 (10.012)	9.689 (10.084)
Web_Portals	7.841 (6.192)	7.977 (6.252)	1.757 (9.073)	1.231 (9.139)	12.454 (8.482)	12.268 (8.674)	5.659 (8.297)	6.558 (8.356)
Patent	9.435 (9.920)	7.091 (10.254)	-6.573 (14.468)	-14.392 (14.979)	31.099** (15.658)	30.952* (16.021)	18.167 (12.584)	19.291 (12.936)
y2008	1.348 (3.038)	0.743 (3.065)	-2.097 (4.528)	-2.624 (4.567)	-0.503 (4.862)	-0.264 (4.940)	1.950 (3.859)	1.116 (3.885)
y2010	-0.549 (2.778)	-0.907 (2.793)	-2.759 (4.179)	-3.023 (4.185)	-1.242 (4.586)	-1.139 (4.669)	-3.190 (3.554)	-3.541 (3.562)

y2012	-1.134 (2.922)	-1.160 (2.948)	-5.952 (4.419)	-5.591 (4.433)	-1.262 (4.691)	-1.091 (4.771)	-1.693 (3.692)	-1.545 (3.720)
y2014	8.727*** (2.859)	8.440*** (2.885)	4.123 (4.394)	3.943 (4.443)	10.766** (4.554)	11.161** (4.624)	4.873 (3.614)	4.719 (3.643)
Constant	8.582 (7.405)	7.809 (7.907)	19.377* (11.167)	15.697 (11.875)	-5.353 (10.575)	-7.418 (11.727)	21.398** (10.536)	21.166* (11.335)
Observations	379	379	305	305	286	286	352	352
R^2	0.380	0.387	0.207	0.228	0.381	0.384	0.278	0.290
Adjusted R^2	0.322	0.321	0.117	0.125	0.302	0.292	0.205	0.207
Residual Std. Error	13.451 (df = 346)	13.464 (df = 341)	17.810 (df = 273)	17.735 (df = 268)	17.717 (df = 253)	17.844 (df = 248)	16.714 (df = 319)	16.699 (df = 314)
F Statistic	6.617*** (df = 32; 346)	5.830*** (df = 37; 341)	2.303*** (df = 31; 273)	2.204*** (df = 36; 268)	4.862*** (df = 32; 253)	4.184*** (df = 37; 248)	3.831*** (df = 32; 319)	3.470*** (df = 37; 314)
Note:								*p<0.1; **p<0.05; ***p<0.01

Since we analyzed the business-idea and business-plan proposals in isolation, we present the results for each hypothesis separately for each stream.

Hypotheses 1a–1b: Heterogeneity test on opportunity evaluations in general and when comparing opportunities at different stages

Following the approach used by Gruber et al. (2015), we tested for heterogeneity in opportunity evaluations by calculating pooled ordinary least-squares (OLS) estimations on two different levels: first on the evaluation scores from all types of jurors overall, and second for the three distinct groups of jurors.

As shown in **Tables 5a and 5b**, the three types of jurors placed different emphasis on specific attributes of the business opportunity. Nevertheless, for both business ideas and business plans, most of the study variables did not have a significant impact on the score results for the three distinct types of jurors.

We then further explored the (potential) impact of the jurors' professional role by calculating one-way ANOVAs for all combinations of the three types of jurors (**Tables 6a & 6b**). For business ideas, neither the comparisons of any two types of jurors, nor all three, show significant differences. In contrast, for business plans, ANOVA reveals significant differences when considering all three types of jurors, and when comparing investors with either of the other two types in isolation. In particular, when considering business plans with all three types of jurors, ANOVA yielded an F-statistic of 6.958, which was significantly different from zero ($p = .001$) (**Table 6b**).[15] The results provide partial support for Hypothesis 1a (general heterogeneity in opportunity evaluations). Furthermore, the fact that the differences between the three types of jurors are significant for business plans but not business ideas provides support for Hypothesis 1b (differences in opportunity evaluation depending on stage of maturity).

[15] In this context, it has to be admitted that pooling all evaluations from 2004 to 2014 for computing the ANOVA ignores the general variations in the mean evaluation scores between the different editions of the competition.

Table 6a: ANOVA to determine differences between the mean score points that the three types of jurors awarded to business ideas.

Business Ideas		Df	Sum Sq	Mean Sq	F value	Pr(> F)
E-M-I	Class	2	1'175	587.7	1.487	0.227
	Residuals	1'041	411'454	395.2		
E-M	Class	1	91	90.5	0.231	0.631
	Residuals	694	272'445	392.6		
E-I	Class	1	1'108	1'107.6	2.875	0.090
	Residuals	694	267'388	385.3		
M-I	Class	1	565	564.9	1.385	0.240
	Residuals	694	283'076	407.9		

Table 6b: ANOVA to determine differences between the mean score points that the three types of jurors awarded to business plans.

Business Plans		Df	Sum Sq	Mean Sq	F value	Pr(> F)
E-M-I	Class	2	4'645	2'322.7	6.958	0.001
	Residuals	570	190'284	333.8		
E-M	Class	1	90	89.6	0.258	0.611
	Residuals	380	131'750	346.7		
E-I	Class	1	2'886	2'885.9	8.929	0.003
	Residuals	380	122'815	323.2		
M-I	Class	1	3'993	3'993.0	12.040	0.001
	Residuals	380	126'002	332.0		

Notes on Tables 6a & 6b:

1) Deviating from the descriptive statistics (**Tables 4a & 4b**) and from the OLS regression (**Tables 5a & 5b**) the calculation of the ANOVA estimates in **Tables 6a & 6b** are only based on projects that have been evaluated by at least one juror from all three categories (**E**: Entrepreneurs; **M**: Managers; **I**: Investors).
2) The mean score points awarded to the projects may vary significantly for the specific editions of the competition (see year dummy variables in **Tables 5a & 5b**). The resulting effect from varying mean score points over time has been neglected in the ANOVA analysis.
3) Post Hoc tests were carried out using Tukey tests.

Hypothesis 1c: Entrepreneurs and managers are relatively similar in their preferences compared to investors

Hypothesis 1c, which proposes that the similarity in judgments between entrepreneurs and managers is greater than any combination including investors, cannot be finally determined from the regression results (**Tables 5a, 5b**).

To determine whether the differences between the types of jurors are significant, we ran ANOVA analyses considering only projects that had been evaluated by at least one juror from each of the three categories (**Tables 6a & 6b**). The results show that there are no significant differences between entrepreneurs' and managers' judgments for either business ideas or business plans. However, for business plans, the ANOVA statistics indicate that there are significant differences between investors and entrepreneurs ($p = .003$) and between investors and managers ($p = .001$).

Hypothesis 2: Entrepreneurs' affinity with power cues

Taking all judgments by all types of jurors together, the results for business ideas (**Table 5a**) demonstrate that power cues have a significant and positive influence on score ($B = 1.506$; $p = .014$). The strong positive overall influence is mainly driven by the significant positive effect that power cues have on entrepreneurs ($B = 2.191$; $p = .018$).

As opportunities mature into business-plan proposals (**Table 5b**), the positive effect size of power cues on entrepreneurs becomes even greater ($B = 3.484$; $p = .038$). For business plans there may still be a positive relationship overall, but the effect is no longer significant at the 5% level ($B = 1.716$; $p = .133$). This is due to the fact that the positive impact of power cues on managers and investors is not only considerably lower in magnitude, but also insignificant for these two types. Taken together, the results provide support for Hypothesis 2 (power cues are more appealing to entrepreneurs than to managers and investors).

Hypothesis 3: Managers are less keen on proposals that contain many risk cues

As depicted in **Tables 5a and 5b**, the analysis revealed that risk cues do not have a significant impact on managers' opportunity evaluation. In the earlier (business-idea) stage, they tend to allocate lower scores the more risk cues are present. As the opportunity matures, and more details become available, managers tend to honor opportunities that utilize *more* risk cues. However, although the effect in the business-idea phase is in the expected direction, neither effect is significant. As a result, Hypothesis 3, which suggested that managers are more wary of risk cues, is not supported.

Hypotheses 4a–4c: Cues related to affiliation, achievements, and rewards are especially appealing to investors

For business ideas, the results indicate that affiliation cues (B = .670; p = .231) as well as achievement cues (B = -.254; p = .781) have only insignificant effects on investors' judgment. Most surprising, however, is the result on reward cues: Contrary to our expectations, reward cues have a significant negative effect on the judgment of investors (B = -5.110; p = .002). In other words, investors have a strong aversion towards business ideas containing plentiful statements related to rewards. For more mature proposals, at the business-plan stage, we find a consistent tendency for investors to reject reward cues — however, the effect is no longer significant (B = -3.106; p = .351). Furthermore, for business-plan proposals, cues related to affiliation and achievements do not have a significant impact on investors' judgments either. In summary, Hypotheses 4a, 4b, and 4c (investors have a particularly strong affinity for business opportunities with cues related to affiliation, achievement, and rewards) are not supported, neither for business ideas nor business plans.

Although the individual study variables here do not support the hypotheses, the picture partly changes when we take all five in aggregate and look at the overall model (Model 1). For business ideas, the F-statistic for joint significance of the study variables on the overall score points is 5.707 Thus, for business ideas the study variables are jointly statistically significant at the 1% level. In turn, for business plans, the F-statistic is 5.830 and statistically significant at the 1% level.

Table 7: Results summary.

Nr.	Description	Business Idea	Business Plan
H1a	Individuals with diverse professional roles differ in the evaluation of given business opportunities.	Not supported	Supported
H1b	Individuals with diverse professional roles evaluate business opportunities differently depending on the opportunities' stage.	Supported	
H1c	Individuals with managerial and entrepreneurial roles evaluate a given business opportunity in a more similar way than those with investment roles.	Not supported	Supported
H2	The relationship between the number of power cues in a proposal and its evaluation is more positive for entrepreneurs than for managers or investors.	Supported	Supported
H3	The relationship between the number of risk cues in a proposal and its rating is more negative for managers than for entrepreneurs and investors.	Not supported	Not supported
H4a	The relationship between the number of affiliation cues in a proposal and its rating is more positive for investors than for entrepreneurs and managers.	Not supported	Not supported
H4b	The relationship between the number of achievement cues in a business idea/plan proposal and its rating is more positive for investors than for entrepreneurs and managers.	Not supported	Not supported
H4c	The relationship between the number of rewards cues in a proposal and its rating is more positive for investors than for entrepreneurs and managers.	Not supported	Not supported

6. Discussion

6.1. Implications for entrepreneurship research

By comparing certain attributes from a total of 1072 business opportunities (**Tables 3a, 3b**) with their evaluation by a pool of 114 entrepreneurs, 118 managers, and 100 investors (**Table 3c**), this study extends the work of Gruber et al. (2015) on how individuals with different professional roles diverge in their preference for particular opportunity attributes. To our knowledge, this is the first study that has jointly analyzed and compared the preferences of the three key stakeholder groups (entrepreneurs, managers, and investors) based on actual business-opportunity proposals. To uncover preferences for certain text cues we employed a novel psycholinguistic approach (Pennebaker et al., 2015), which has increasingly been used in behavioral sciences (e.g. Riordan and Kreuz, 2010; Holtzman et al., 2010; Tull and Roemer, 2007) as well as general management research (e.g. Nadkarni and Chen, 2014; Crilly et al., 2015; Gamache et al., 2015; Pfarrer et al., 2010). Most recently, the linguistic research approach is gradually finding its way into entrepreneurship research (e.g. Wolfe and Shepherd, 2015; Moss et al., 2015). The chosen approach is also a response to scholars' call for deploying more innovative techniques in analyzing large datasets (e.g. Feldman et al., 2015).

Three aspects make the results of the study especially unique. First, the study is based on actual business opportunities instead of experimental settings that are often based on a limited number of simplified and fictional cases. Second, the comparative analysis includes three essential target audiences, instead of focusing only on the views of one group with a particular professional role (for example, comparing the evaluation behavior of different (sub-)types of financial investors; e.g. Knockaert et al. (2010), Mason and Stark (2004), and Pontikes (2012)). Third, the study provides insights into how jurors' preferences for certain attributes vary between two stages: the business-idea and business-plan phases.

As long as there is only rough initial information available (in the form of a business-idea proposal), people's professional role does not have significant effects on their evaluation. However, once more detailed business-plan proposals are available, the situation changes, and the individual's professional role *does* affect their judgment (**Tables 6a, 6b**). This result underpins the frequently expressed request for a differentiated approach when conducting research on opportunity beliefs, since all opportunities are not equally appealing to all people (Dimov, 2010; Wood et al., 2014).

The result to which in many cases the study variables did not show significant effects on the evaluation score further underpins the suitable analogy with the origins of the research framework (**Figure 2**): whereas the atomic scientists often noticed that the alpha particles went straight through the object of study, also in our case the results indicate a number of the cues have passed straight through the opportunity template, without causing significant upward/downward deflections in terms of the evaluation score (**Table 7**). In other words, using the atomic structure metaphor, a large number of cues seems to not have struck a nerve in the jurors' opportunity template. We can only speculate on jurors' limited responsiveness to the five cues in the earliest phase, the business-idea stage. One explanation could be that when faced with only rough information, people apply a simplified, more generalized opportunity template that leads to more homogeneous results. Another explanation might be that the limited volume of information contained in a business-idea proposal, used as the input parameter to individuals' opportunity templates, restricts the scope to arrive at significantly different evaluation results, almost irrespective of any differences in one's opportunity template. At that stage, when the proposal consists of just a few pages of text, differences in the jurors' preferences are less salient simply because there are fewer cues present for their preferences to latch on to. Even though we found that people differ in their evaluation behavior for business-idea proposals as compared to business plans (Hypothesis 1b), we cannot be sure whether this is because a different opportunity template is being used (the evaluation model itself), or because information is limited (input parameters to the model).

At a deeper level, the regression analysis reveals insights into preferences for specific opportunity attributes. The results indicate that, for a given business opportunity, cues related to power are especially appealing to entrepreneurs, and less so to managers or investors. Entrepreneurs' strong preference for power cues applies to both business-idea and business-plan proposals. In contrast, the results on managers and investors did not support our predictions. Most surprisingly, the results indicate that investors strongly dislike reward cues, and we found empirical evidence that this aversion is reflected in the scores investors granted to business ideas. The finding appears counterintuitive, as one would expect investors to be primarily interested in financial returns, and thus favor opportunities that feature rewards and contain a correspondingly high number of reward cues. In this vein, one might naturally expect investors to criticize the neglect of reward focus by the technological originators, who typically have a strong emotional attachment to their discovery/idea and hence are supposed to have a strong product (or service) focus. However, the empirical findings suggest that, particularly in the early business-idea phase, founding teams should take care when elaborating on (potential) rewards. The results indicate that in the infancy stage (typically, the phase with the highest degree of uncertainty) investors dislike proposals emphasizing potential (financial) rewards — most likely because these discussions are highly speculative and often over-optimistic.

Nevertheless, the negative relationship between rewards cues and score must be interpreted with due caution regarding imputations of causality. For instance, it could also simply be that, in poor proposals, the authors include extensive elaborations on potential rewards because they lack a compelling product or service to present. In these cases, it is less the plethora of rewards cues that leads to the poor rating, more the technical weaknesses in the product or service, which the venture team is trying to cover up. Still, remarks on (potential) rewards should be deployed carefully in business-plan and, especially, business-idea proposals — a finding that deserves more attention in entrepreneurship research but also practice.

6.2. Practical implications for entrepreneurs and contest organizers

Implications for entrepreneurial founders

Based on this research, the most important, yet basic advice to founders is that they should shy away from speculations on potential rewards, particularly in the earliest, business-idea phase. Even for professional experts, it's hard to make reliable financial projections in the very early phase of a new venture opportunity, and this applies even more to less-experienced, possibly unskilled founders. Instead, in the business-idea phase, the venture team should focus on describing their product or service, its benefits to customers, or the problem that it aims to solve.

Our findings also indicate that founders should spend time learning about the roles and the related preferences of those to whom they send their proposals. If approaching one particular target group, or a number of groups with similar preferences, the venture team should customize their business-plan proposal and emphasize those aspects that are particularly attractive for the specific target audience (cf. Mason and Stark, 2004; Petty and Gruber, 2011). In this vein, instead of creating a single, monolithic plan and then tinkering with it, venture teams could focus on developing discrete modules of text on various themes that can then be edited together in different configurations to suit different audiences.

Furthermore, the results have also implications for founders who personally have less of a product/service focus. For example, venture founders who possess an investment role themselves might be more likely to include more rewards cues when writing a proposal. For these cases, the results suggest that their proposal drafting input should be balanced with contributions or feedback from someone with more product or customer focus. The input of an external professional editor might also help founding teams achieve the "right" balance (in whatever context) in their proposals. For instance, if teams choose to write in a language that is more "popular" with evaluators (i.e. English), but in which they themselves may not be completely fluent, a native speaker could help make language cues as precise as possible, and avoid misunderstandings in sensitive areas such as speculation on potential rewards. Just as founding teams can get too close to their product, so they can get too close to the proposal that describes it.

The findings might also support some wider applications — for example, in a context with an internal perspective, such as organizational members preparing a proposal for a new product or project that will be considered by the (entrepreneurial) founder of their firm and/or some of its managers. If a new project can be considered as a mini-business in its own right (i.e. it will become a discrete profit center within the organization), some of the same observations may apply to it as for startup firms.

Entrepreneurial founders should be aware of the fact that the text cues in their proposals, and the underlying opportunity attribute they relate to, may have heterogeneous effects on audiences and thus lead to varying judgments of the same proposal. Two evaluators with different professional roles may view the same proposal quite differently simply due to effects from the language cues used in the presentation.

Implications for startup competition organizers

The study reveals important insights into individuals' evaluation of a given business opportunity, and raises issues for the design of business idea and/or plan contests. First and foremost, the organizers of a startup competition, but also coaches on entrepreneurship, should discourage (potential) founders from speculating on (financial) rewards, especially in the business-idea phase.

Next, to obtain a deeper understanding of the preferences of each type of juror and to investigate the drives behind their allocated scores, we decomposed the total score that each juror awarded to a project and ran additional analyses on the individual question (**Tables 2a & 2b**) level[16]. The question-level analysis reveals that the correlation between the score for a specific question and the total score awarded by the jurors is quite high (for most questions $\rho > .800$). Given the relatively small number of questions in the evaluation form (in this empirical setting, on investors' form in particular), a high correlation between question score and total score was to be expected. Across all types of jurors, this result suggests that jurors form an overall opinion on a certain project first; and based on this opinion, seem to follow a relatively fixed score distribution system, in which the scores each juror awards to single questions increase or decrease in an approximately linear fashion. In other words, some questions are generally rated more poorly, but based on their overall impression, jurors shift their score points up or down throughout all questions (almost) equally. This result is relevant to many others as well as organizers of a business-plan competition, since it implies that a more detailed assessment questionnaire barely affects people's rating of a business opportunity. Restricting evaluation to a single overall project rating instead of individual question ratings, when considering a large number of projects, would probably not lead to significant changes in the projects' total assessment or comparative ranking.

Nevertheless, a partitioned evaluation design is to be recommended for three reasons. First, the individual question rating may prompt the jurors to follow a more structured evaluation process and consider a range of predefined criteria — otherwise, some aspects might be neglected. Second, organizers promote their competitions to participants with the prospect of getting feedback on their business idea/plan proposals from experienced industry experts. To meet this promise and provide a structured, topic-specific feedback, the organizers of our focal event opted for an evaluation design consisting of individual ratings on specific questions (**Tables 2a & 2b**) combined with a call for jurors to add written comments on each individual question rating. Third, a differentiated questionnaire plays a pivotal role in the final stage of evaluation, when it comes to determining the winners of the competition. The finding that single question ratings followed the overall impression was derived by analyzing a pool containing a large number of good and weak business idea and plan proposals. However, once all projects have gone through the general assessment process, the top projects are further scrutinized by jury committees, and the teams are invited to pitch their project to a jury of industry

[16] On the individual-question level, for the documents in English language the dataset contains a total number of 9942 ratings by entrepreneurs, 8937 ratings by managers, and another 5063 ratings by investors (business idea and business plan together).

experts. When considering only a small number of top projects during this due diligence process, which are typically all very close to one another in terms of quality, the details on specific strengths and weaknesses are decisive for determining the winners. For these three reasons, organizers of third-party evaluation of business opportunities should deploy an assessment questionnaire that has to be rated and possibly commented point by point, and not use an aggregate point score.

Taken together, individuals with different professional roles vary in their preferences when evaluating business-plan proposals. People's overall impression of a business opportunity seems to be decisive for their judgment, and the assessment of individual attributes (evaluation questions) seems to follow their overall opinion. Due to the heterogeneity in individuals' preferences, particularly when assessing business plans (Hypothesis 1a), and the consequential variations in the total score they give a project, the organizers of a competition should take this finding into account when assigning the jurors to projects. To mitigate unfair rating biases, a (similarly) balanced number of jurors from each professional domain should vet the business opportunities, at least those on the shortlist.

6.3. Limitations and directions for future research

When interpreting the results of this study, several limitations should be kept in mind. First, language: Out of all 1837 projects that participated in the competition (in either track) from 2004 and 2014, a total of 1072 proposals have been written in English, 641 in German, 118 in French, and six in Italian. The question arises of whether sample selection bias is evident in our data because we focused solely on proposals in English. There may be (omitted) independent variables that are systematically correlated with the language of the submitted proposal and the score that a project achieves. To check whether there is such a relationship between language used and score, we ran additional regressions on the whole population (all proposals in any language) based on the control variables and supplementary language dummies. The result revealed that proposals in English score higher than those in German. This is quite remarkable, given that most participants' and judges' native tongue is German, and only rarely English. Future research could e.g. analyze how market focus, growth ambitions, and VC market restrictions drive venture teams' decisions on which language to use for their business idea/plan proposals, and how this decision is related to external judgments.

A second limitation arises from the fact that different types of jurors used different evaluation forms (one for entrepreneurs and managers, but a different one for investors). Future research may validate the findings by using non-experimental data, as we did, but maintaining an identical evaluation questionnaire for all types of jurors.

Third, the business idea/plan competition setting only focuses on the very early stage. It is not clear how (or indeed whether) the projects evolved after the competition. To validate the accuracy of juror evaluations, future research should apply a retrospective view and compare competition ratings with performance indicators of the project in later stages. In the same context, the independent (study/control) variables from a startup competition setting could also be connected to effective performance measures.

In this way, ongoing research could explore more accurate indicators/approaches for predicting commercial potential based on business ideas/plans.

Fourth, in our hypothesis development, we assume that peoples' attitudes towards certain opportunity attributes (affiliation, achievement, power, reward, risk) reflect their preferences in others' business idea/plan proposals. Research on VCs' investment selection behavior has found empirical evidence that VCs tend to favor entrepreneurial teams that are similar to themselves (e.g. Franke et al., 2006; Cable and Shane, 1997). Whereas this assumption for all types of jurors may find support from the vast literature on homophily (e.g. McPherson et al., 2001; Ruef et al., 2003; Phillips et al., 2013), it remains unclear whether this theory can be extended to people's evaluation of business opportunities in which they do not hold any personal stake. Therefore, what people seek for themselves may be independent from how they evaluate others' business opportunity proposals.

Fifth, it can hardly be discerned how much jurors draw their ratings from the information presented in the proposal, and how much they triangulate/validate this information with their own industry expertise. For example, negative judgments may be due to poor (or missing) detail in the proposal, or a lack of credibility in whatever information *is* present. The organizers of the competition strive to assign jurors who possess solid professional expertise in the relevant field. Thus, irrespective of the form/content of the details in the proposal, jurors may doubt its reliability (e.g. technical feasibility, market opportunities, team managerial/technical expertise, ability to enforce intellectual property rights) and therefore give it an adverse rating.

Sixth, future studies can examine whether the preferences by the jurors in the Swiss startup competition also hold for external opportunity evaluations in other countries where language conventions are likely to be less permissive. For example, few (if any) UK contests would allow submissions to be written in German; Switzerland is a fairly unusual case in terms of its multi-language culture.

Seventh, the results may not equally apply to all industries. Although the analyzed startup contest is open to companies from any industry, the participating ventures are mostly rooted in scientific or technological research from two universities.

7. Conclusion

The phenomenon-driven investigation in this paper provides evidence that individuals' professional role shapes their focus on certain characteristics of a given business opportunity, and thus may lead to different perceptions of its attractiveness. The comparative analysis reveals that this divergence comes into effect in the business-plan stage, but not at the earlier business-idea stage. We found that the business-plan judgment by entrepreneurs, managers, and investors differed when considering their overall assessment of a given business opportunity. Nonetheless, when digging a level deeper and searching for the drivers of these differences by looking at the impact of certain linguistic cues, the effects from single cues on the assessment by each type of jurors are mostly insignificant but tend to the same direction.

Most notably, and counterintuitively, an emphasis on (potential) rewards in a business opportunity proposal tends to have a strong negative effect on the judgment of all types of jurors — ironically, investors in particular.

Acknowledgement

The authors are grateful for research assistance by Martin Sterchi and for helpful comments and suggestions by Stefano Brusoni and Tom Albrighton. Furthermore, the authors are indebted to Lea Firmin and Silvio Bonaccio for granting research access to the »venture» database.

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Paper 2: Supplementary Information

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Is value in the eye of the beholder? An empirical study of how entrepreneurs, managers, and investors evaluate business opportunities at the earliest stages

Note: The following results from the question-level analysis have been omitted from Paper 2 (as presented in the preceding chapter of this doctoral dissertation and, hence, from the manuscript version submitted to the journal) for the sake of brevity and focus. To provide a better understanding on what has been analyzed the following section, **Tables 2a & 2b** have been copied from Paper 2.

Additional insights from a question-level analysis

To obtain a deeper understanding of the preferences of each type of juror and investigate the drives behind the jurors' score point allocation, the authors decomposed the total score that each juror awarded to a project and ran additional analyses on the individual question (**Tables 2a & 2b**) level[17]. The results are presented in the **Supplementary Tables S1a & S1b**.

For business ideas, the analysis shows that the question on *revenue mechanism: realistic estimate of costs and price, attractive margins* was the worst-rated question by both entrepreneurs (mean = 3.829 points) and managers (mean = 3.782 points). In other words, entrepreneurs and managers regard *realistic estimate of costs and price, attractive margins* to be most weakly satisfied criterion in the evaluation questionnaire. Nevertheless, *overall impression, clear presentations, consistent figures* is the dominant question, with the highest correlation to total score for both entrepreneurs ($\rho = .901$) and managers ($\rho = .917$) alike—even when controlling for the weights of the individual questions on the total. In contrast, for business-idea assessment by investors, the lowest-rated question is on *subjective impression attractiveness of investment;* this is also the central question, with a mean score of 3.837 and a weighted correlation of $\rho = .969$ with investors' total scores.

For business plans, the question on *risk identification, risk assessment, countermeasures* was the worst-rated by both entrepreneurs (mean = 4.789) and managers (mean = 4.789). Regardless of this low scoring, *overall impression: conciseness, consistency, presentation* exhibits the strongest correlation with the total scores awarded by entrepreneurs ($\rho = .919$) and managers ($\rho = .944$), when controlling for the questions' weights. Looking at investors' business-plan judgments, they are least satisfied with *risk identification, risk assessment, countermeasures* (mean = 4.544), while the question on *business potential* exhibits the strongest correlation with their total scores ($\rho = .929$). In other words, investors' views on business potential are most indicative of their overall judgment on whether a business plan (project) is strong or weak.

[17] On the individual-question level, the examined dataset contains 9912 ratings by entrepreneurs, 8925 ratings by managers, and another 5070 ratings by investors (business idea and business plan together).

However, one limitation to the explanatory power of the question-level analysis is the fact that the number of questions in the evaluation form was quite small (Tables 2a & 2b), especially for investors. (However, the number of questions generally exceeded the four evaluation criteria used by all judges in Foo et al. (2005).) Based on the small number of questions, it is important to note that there is a high correlation between score per question and total score (**Supplementary Tables S1a & S1b**).

Table 2a: Evaluation questionnaire for business idea projects.

Nr.	Topic Area	Criteria	Weight
*Juror types: Entrepreneurs and managers**			
1	Customer benefit	Differentiated vis-à-vis comparable products	12.5%
2		Provides a solution to a customers' need	12.5%
3	Market and competition	Sustainable competitive advantage	12.5%
4		Sales potential	12.5%
5	Revenue mechanism	Realistic estimate of costs and price, attractive margins	25.0%
6	Overall impression	Subjective impression 1) Mandatory entry: overall impression, clear formulation/presentations, consistent figures. 2) If available (does not count towards the evaluation): impression of the team (competencies, composition, etc.)	25.0%
Juror type: Investor			
7	Business potential	Sound business concept, attractive product	25.0%
8		Market is attractive	25.0%
9	Financing potential	Subjective impression 1) Mandatory entry: attractiveness of investment (appropriate returns). 2) If available (does not count towards the evaluation): impression of the team (competencies, composition, etc.)	50.0%

* The organizers of the competition only distinguished between investors and non-investors (labelled as "entrepreneurs"). We decomposed the organizer's juror category "entrepreneur" into effective entrepreneurs (those who had actually co-founded a new firm) and managers.

Table 2b: Evaluation questionnaire for business plan projects.

Nr.	Topic Area	Criteria	Weight
*Juror types: Entrepreneurs and managers**			
10	Executive Summary	Completeness, attractiveness, conciseness	10.0%
11	Product idea	Customer need, target customer identification, product differentiation	10.0%
12	Management team	Competencies, composition	10.0%
13	Marketing	Market analysis, market segmentation, marketing strategy	10.0%
14	Business system/organization	Effectiveness, appropriateness, partnerships	10.0%
15	Implementation plan	Development steps, critical path	10.0%
16	Risks	Risk identification, risk assessment, countermeasures	10.0%
17	Financing	Revenue mechanisms, costs/margins, liquidity planning, capital requirements	10.0%
18	Overall impression	Consciseness, consistency, presentation	20.0%
Juror type: Investor			
19	Business potential	Market attractiveness, product potential, business concept, growth potential	25.0%
20	Management team	Competencies, composition	25.0%
21	Risks	Risk identification, risk assessment, countermeasures	25.0%
22	Financing potential	Investment attractiveness, returns, quality of deal proposals	25.0%

* The organizers of the competition only distinguished between investors and non-investors (labelled as "entrepreneurs"). We decomposed the organizer's juror category "entrepreneur" into effective entrepreneurs (those who had actually co-founded a new firm) and managers.

Supplementary Table S1a: Question level analysis for business ideas.

Entrepreneurs

Nr.	Short description	Item.total	Item.Tot.woi	Difficulty	Item.Criterion
1	Differentiated vis-à-vis comparable products	0.877	0.817	4.848	0.858
2	Provides a solution to a customer's need	0.835	0.761	5.803	0.808
3	Sustainable competitive advantage	0.861	0.798	4.237	0.842
4	Sales potential	0.840	0.762	4.684	0.819
5	Realistic estimate of costs and price, attractive margins	0.817	0.731	3.829	0.858
6	Overall impression, clear presentations, consistent figures	0.901	0.852	5.035	0.919

Managers

Nr.	Short description	Item.total	Item.Tot.woi	Difficulty	Item.Criterion
1	Differentiated vis-à-vis comparable products	0.857	0.788	4.856	0.835
2	Provides a solution to a customer's need	0.838	0.765	5.743	0.813
3	Sustainable competitive advantage	0.857	0.792	4.144	0.836
4	Sales potential	0.869	0.806	4.416	0.858
5	Realistic estimate of costs and price, attractive margins	0.843	0.768	3.782	0.880
6	Overall impression, clear presentations, consistent figures	0.917	0.877	4.844	0.934

Investors

Nr.	Short description	Item.total	Item.Tot.woi	Difficulty	Item.Criterion
7	Sound business concept, attractive product	0.945	0.875	4.474	0.931
8	Market is attractive	0.928	0.837	4.464	0.905
9	Subjective impression attractiveness of investment	0.943	0.871	3.837	0.969

Legend on Supplementary Table S1a:

Item.total	Correlation between item score and total score (sum of individual scores)
Item.Tot.woi	Correlation between item score and total score without item
Difficulty	Mean of the item score
Item.Criterion	Correlation between item score and total score as reported (with weights)
Grey shading	*Maximum amount (column)*

Supplementary Table S1b: Question level analysis for business plans.

Entrepreneurs

Nr.	Short description	Item.total	Item.Tot.woi	Difficulty	Item.Criterion
10	Completeness, attractiveness, conciseness	0.797	0.740	6.045	0.794
11	Customer need, target customer identification, product differentiation	0.828	0.782	6.112	0.825
12	Competencies, composition	0.772	0.713	5.969	0.769
13	Market analysis, market segmentation, marketing strategy	0.855	0.814	5.698	0.850
14	Effectiveness, appropriateness, partnerships	0.860	0.820	5.450	0.856
15	Development steps, critical path	0.844	0.796	5.343	0.841
16	Risk identification, risk assessment, countermeasures	0.766	0.689	4.789	0.761
17	Revenue mechanisms, costs/margins, liquidity, capital	0.847	0.802	5.079	0.846
18	Overall impression: Conciseness, consistency, presentation	0.919	0.892	5.992	0.937

Managers

Nr.	Short description	Item.total	Item.Tot.woi	Difficulty	Item.Criterion
10	Completeness, attractiveness, conciseness	0.887	0.855	5.901	0.885
11	Customer need, target customer identification, product differentiation	0.882	0.850	5.953	0.882
12	Competencies, composition	0.855	0.816	5.796	0.850
13	Market analysis, market segmentation, marketing strategy	0.916	0.892	5.389	0.914
14	Effectiveness, appropriateness, partnerships	0.908	0.883	5.292	0.906
15	Development steps, critical path	0.899	0.871	5.204	0.897
16	Risk identification, risk assessment, countermeasures	0.844	0.800	4.789	0.841
17	Revenue mechanisms, costs/margins, liquidity, capital	0.907	0.880	5.117	0.906
18	Overall impression: Conciseness, consistency, presentation	0.944	0.927	5.789	0.955

Investors

Nr.	Short description	Item.total	Item.Tot.woi	Difficulty	Item.Criterion
19	Market attractiveness, product potential, concept, growth potential	0.929	0.871	5.402	0.929
20	Competencies, composition	0.911	0.840	5.154	0.911
21	Risk identification, risk assessment, countermeasures	0.877	0.785	4.544	0.877
22	Investment attractiveness, returns, quality of deal proposals	0.923	0.856	4.623	0.923

Legend on Supplementary Table S1b:

Item.total	Correlation between item score and total score (sum of individual scores)
Item.Tot.woi	Correlation between item score and total score without item
Difficulty	Mean of the item score
Item.Criterion	Correlation between item score and total score as reported (with weights)
Grey shading	*Maximum amount (column)*

Reference

Foo, M.-D., Wong, P. K., & Ong, A. (2005). Do others think you have a viable business idea? Team diversity and judges' evaluation of ideas in a business plan competition, *Journal of Business Venturing,* 20(3), 385-402.

Paper 3

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Nanobiotech in big pharma: A business perspective

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The combination of techniques from previously disparate research areas such as nanotech and biotech ('nanobiotech') provides considerable opportunities for innovation[1]. For example, drug development capitalizes on nanotechnologies where deliberately designed nanosystems encapsulate and deliver drug agents to target cells in the body. In medical research, microelectronic devices that contain biological components have become useful tools to explore biological functions, and *in vitro* metabolic engineering research is directed at controlling animal and human physiological functions on a chip[2]. On 10 September 2015, Proteus Digital Health (Redwood City, CA, USA) and Otsuka Pharmaceutical (Chiyoda-Ku, Japan) hit an important milestone, when the US Food and Drug Administration (FDA) accepted their joint drug/device application for regulatory approval: a 'smart pill' that contains an ingestible sensor to measure medication compliance and physiological response[3]. It is the first 'digital medicine' application of its kind that has been accepted by the FDA[4]. Nevertheless, these progresses should not obscure the fact that in medical therapeutics and diagnostics, most nanobiotech applications are exclusively used in (academic) research and clinical trials, whereas the number of existing applications available on the market is still considerably lower.

Since the early 2000s, various reports on nanobiotech – especially those reporting scientific advancements - have created the impression that nanobiotech has gained considerable economic importance. Here, we re-examine whether nanobiotech has already taken hold as a significant addition to the intellectual property (IP) portfolio within the established pharmaceutical industry (big pharma), particularly in comparison to the established biotech field, and to what extent big pharma is already capitalizing on this new technological area.

To assess the impact of integrating nano- and biotechnological innovation into the pharmaceutical industry, we analysed data from company annual reports and from the world patent database 'Derwent Innovations Index' for 25 big pharma companies (**Supplementary Information**). For this company group, we identified a total number of 86'664 different patents from various technological fields with priority application date between 1994-2013. Based on International Patent Classification (IPC) codes, we determined the number of different nanotech and biotech related patents held by the companies in our sample.

Much biotech, little nanotech

When analysing the technological classification of big pharma's patent portfolio from 1994 to 2013, the proportion of biotech related patents compared to the total number of patents ranged from approximately 20% to 30% (**Figure 1**).

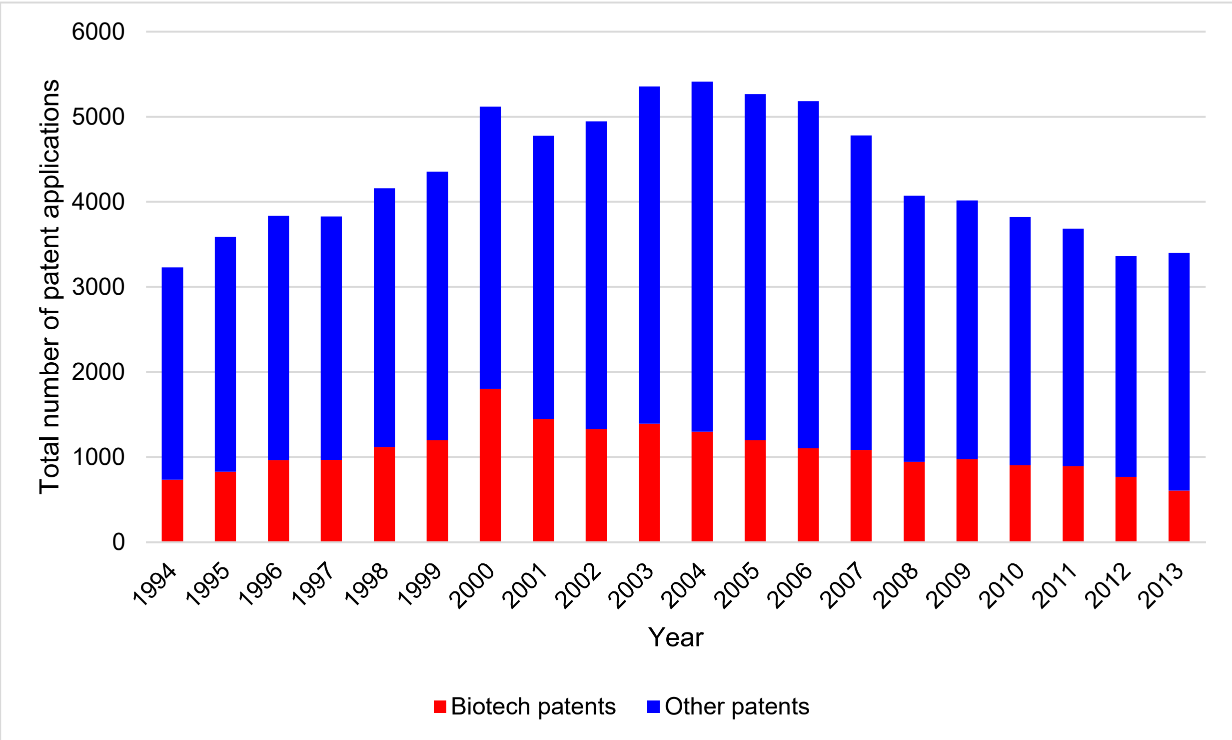

Figure 1: Patent applications of 25 big pharma companies per year.

Note: As data for most recent patent applications have not been published yet and to avoid the resulting bias, the time span in the figure has been upside limited to the year 2013.

Source: Derwent Innovations Index

In contrast, only 0.3% of all patents applied for since 1994 were classified as nanotech (**Figure 2**). Thus, nanotech related patents represented a very small proportion of patents in big pharma's portfolio, even when taking into account that nanotech is considered an enabling or general purpose technology, where one discovery is often applicable to a broad range of uses.

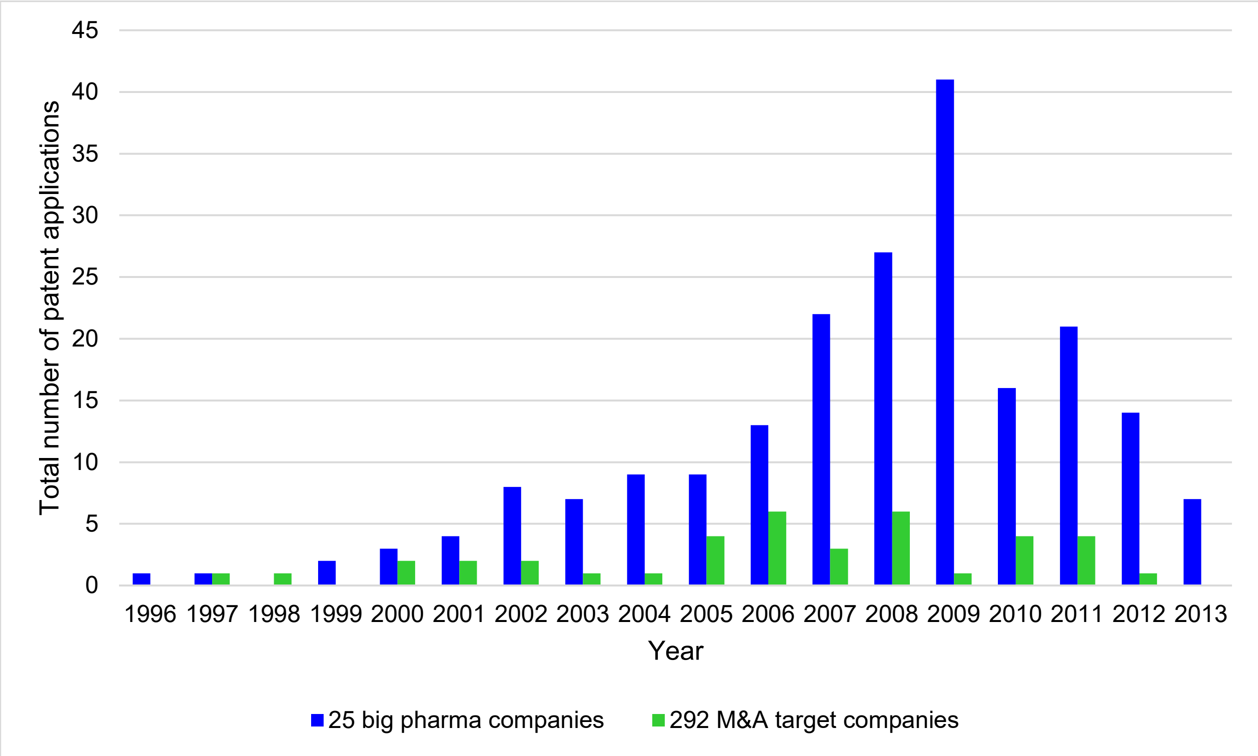

Figure 2: Nanotech patents applied per year.

Note: As data for most recent patent applications have not been published yet and to avoid the resulting bias, the time span in the figure has been upside limited to the year 2013.

Source: Derwent Innovations Index

A possible explanation for this small proportion of nanotech patents in the big pharma companies' portfolio could be that big pharma is not the main driver of the nanobiotech revolution. In many technological areas, new smaller ventures typically are the innovative engines in nascent technologies. However, due to the high development costs in the nanobiotech field, these new ventures often need technological partnerships or, more importantly, financial backing from a major company. Such cooperation agreements oftentimes are a first step towards later trade sales, which allow large companies to complement their in-house IP. To examine if the IP of smaller ventures was a major external source of nanotech IP for established companies, we identified 292 M&A transactions on 292 acquisition targets for the decade 2005-2014, where one of the 25 big pharma companies acted as acquirer firm. Then, we analysed the patent data of each target firm, typically small-to-medium-sized enterprises (SMEs). Surprisingly, our results show that the M&A target firms held only a very small number of nanobiotech related patents (< 10 patents filed per year by entire target sample, see **Figure 2**). It needs to be taken into consideration, however, that acquirers may have filed patents that were based on pre-existing unpatented nanotech related knowledge of the acquired firms after the completion of a M&A transaction. Although the knowledge base of these patents might have been attributable to the M&A targets, the resulting patents were counted towards the acquirers' patent portfolio in the analysis.

What's nanobiotech worth?

Of course, the number of patents filed by a company is a poor proxy for the technical and economic value of the underlying intellectual property. Nevertheless, the relatively small number of nanotech related patents in big pharma's patent portfolio suggest that the commercial importance of nanobiotech in the medical therapeutics area is still minor. As pharma companies do not systematically disclose revenues for individual nanobiotech-based products, we analysed the individual revenues of nanobiotech-based drugs that the 25 pharma companies reported as one of their top-selling products as a proxy for the commercial importance of nanobiotech-based drugs for big pharma. For our sample of 25 big pharma companies, we identified 14 nanobiotech-based drugs for which the companies reported individual product revenues (**Table 1**). In 2015, only four of the identified nanobiotech-based drugs achieved annual revenues ≥USD 1 billion, and most others were even far below this benchmark. In contrast to these blockbuster drugs, most other nanodrugs were even far below and specific revenue data have not even been disclosed separately. In comparison, AbbVie's (North Chicago, IL, USA) biopharmaceutical drug Humira (adalimumab), which headed the ranking of biopharmaceutical drugs by revenue in 2015[5], accounted for annual revenues of about USD 14.0 bn, or 61 percent of AbbVie's total net revenues in 2015. These examples suggest that nanotech-based drugs are still a niche market for big pharma from an economic perspective.

Conclusions

In summary, and unlike often predicted over the last decade, nanobiotech still plays a minor role in the established pharmaceutical industry both in terms of patenting and product revenues. Nanobiotech research is generally a lengthy, costly, and technically highly uncertain process and, by now, academic institutions have mainly driven innovation in this field. As result, most domain experts are in academia and - even more than a decade after the emergence of the nanotech hype[6] - there is still a shortage of skilled and experienced people able to pick up the academic research results, develop them further, and finally commercialize them. Facing the impending loss of patent protection for many blockbuster drugs, big pharma needs to restock its product pipelines with high potential innovations[7]. Technically, nanobiotech is supposed to be the salvation to fill the gap, but there should be more debate on the technology's economic prospects.

ACKNOWLEDGMENTS

The authors thank Adrian Oesch (ETH Zurich) for his valuable research assistance for the patent data retrieve.

Product	Nanotech approach / agent	Indication	Lead company group	Product revenues 2015 ($ millions)	Total company revenues 2015 ($ millions)	% of total revenues
Neulasta	Pegfilgrastim (PEG-rhGCSF)	Chemotherapy-induced (febrile) neutropenia	Amgen	4 715	21 662	21.8%
Copaxone	Copolymer of alanine, lysine, glutamic acid and tyrosine	Multiple sclerosis	TEVA Pharmaceutical	4 023	19 652	20.5%
Xeplion	Nanocrystals	Schizophrenia	Johnson & Johnson	1 830	70 074	2.6%
Renagel	Crosslinked poly(allylamine) resin	Chronic kidney disease	Sanofi	1 029	38 347	2.7%
Abraxane	Paclitaxel protein bound nanoparticles	Cancer	Celgene	968*	9 256	10.5%
Neoral	Cyclosporine nanoemulsion	Immunosuppressant after liver, kidney, or heart transplant	Novartis	570*	50 361	1.1%
Pegasys	PEG-α-interferon 2a	Hepatitis C, chronic	Roche	560	52 503	1.1%
Emend	Nanocrystalline aprepitant	Antiemetic	Merck & Co	535	39 498	1.4%
Mircera	Methoxy polyethylene glycol-epoetin beta	Anemia, kidney failure, chronic	Roche	495	52 503	0.9%
AmBisome	Liposomal Amphotericin B	Fungal infections	Gilead Sciences	350	32 639	1.1%
Somavert	PEG-HGH antagonist	Acromegaly	Pfizer	218	48 851	0.4%
Diprivan	Nanoemulsion, liposomal propofol.	Anesthetic	AstraZeneca	200	24 708	0.8%
Rapamune	Nanocrystalline sirolimus	Immunosuppressant	Pfizer	197	48 851	0.4%
PegIntron	PEG-α-interferon 2b	Hepatitis C, chronic	Merck & Co	182	39 498	0.5%

Table 1: Examples of commercially available nanotherapeutic top products.

The table shows a selection of nanotherapeutic drug products for which the specific revenue data were disclosed in the 2014 annual report of the big pharma company groups in our sample. The listed company groups might also hold commercial rights for other nanotherapeutic products that are not listed in this overview, for example because financial data have not been explicitly disclosed due to insignificant revenue amounts. *Net product sales.

Source: Identification and description of the drugs are based on previous studies[8, 9, 10]; the financial data are retrieved from the companies' 2015 annual reports.

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Paper 3: Supplementary Information

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Nanobiotech in big pharma: A business perspective

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Data sources and methodology

To define our sample of big pharma companies, we identified the top 25 pharmaceutical / healthcare companies based on their US$ market capitalization as per 22 September 2015. Consequently, we selected the following sample of big pharma companies for our analysis:

Company Name	Country of Headquarters	Market Capitalization as of 22 September 2015 ($ millions)
Novartis AG	Switzerland	260 567
Johnson & Johnson	United States of America	257 887
Roche Holding AG	Switzerland	230 014
Pfizer Inc	United States of America	199 945
Gilead Sciences Inc	United States of America	155 185
Merck & Co Inc	United States of America	143 592
Sanofi SA	France	132 697
Novo Nordisk A/S	Denmark	118 117
Allergan plc	Republic of Ireland	112 430
Amgen Inc	United States of America	111 531
Bayer AG	Germany	110 455
Bristol-Myers Squibb Co	United States of America	104 586
AbbVie Inc	United States of America	98 307
GlaxoSmithKline PLC	United Kingdom	97 466
Eli Lilly and Co	United States of America	97 097
Celgene Corp	United States of America	94 185
AstraZeneca PLC	United Kingdom	85 951
Valeant Pharmaceuticals International Inc	Canada	78 322
Biogen Inc	United States of America	69 883
Abbott Laboratories	United States of America	64 536
Teva Pharmaceutical Industries Ltd	Israel	61 453

Regeneron Pharmaceuticals Inc	United States of America	54 891
Mylan NV	United Kingdom	47 347
Shire PLC	Republic of Ireland	44 089
Takeda Pharmaceutical Co Ltd	Japan	37 156

Supplementary Table S1: Company sample.

In a next step, we systematically retrieved patent information for the big pharma company sample from the world patent database 'Derwent Innovations Index'[1]. We identified a total number of 86'664 different patent families. Based on the International Patent Classification (IPC) codes[2], we determined the technical subject area of each patent family: In our analysis, we drew on the IPC subclass codes assigned to a given patent family to determine its technological affiliation. This methodology allows for a clear distinction between biotech, nanotech, and other technological fields, which is sometimes ambiguous and blurred otherwise. One patent family may be assigned to more than one IPC subclass, e.g. to a nanotech and a biotech subclass, simultaneously. A list of biotechnology and ICT-related patent codes is available at OECD website www.oecd.org/sti/inno/40807441.pdf. Nanotechnology-related patents are defined as those with IPC subclass codes B82B and B82Y.

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Paper 4

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Sourcing innovation through M&A: Lessons from nanobiotechnology

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Combining nanotech and biotech opens up new horizons for innovative products and production processes with substantial economic potential. The analysis exemplifies that economically nanobiotech, is in an embryonic stage and is having a slow, but recognizable impact on the big, life sciences industry.

A review of the literature (Paull et al. 2003; Maine et al. 2014; Wagner et al. 2006) suggests that the emergence of nanotech in science and business has followed a similar development path to biotech in the late 1970s and that nanotech is displaying striking parallels with the subsequent craze for biotech. These developments are providing new opportunities for different groups of stakeholders, particularly in areas where nanotech is interfacing with biotech - i.e., the nascent area of nanobiotech. Nanobiotech can be defined as “any application of nanotechnology in biological research, drug discovery and drug delivery devices, diagnostic tools, therapeutics or novel biomaterials” (Paull et al. 2003). From a scientific perspective, interest in nanobiotech is based on the perception that nanotech is offering new tools to biology and that, in turn, biology is providing nanotech with access to new markets and technical applications via novel types of functional nanosystems originating from cellular components (Whitesides 2003). From an economic perspective, in the biotech area, the application of nanotech is associated with advantages related to new materials and devices with various applications. Since the emergence of nanotech in the 1990s, nanoscale materials and methods have infiltrated the life sciences and their techniques are being deployed in various ways. One such example is coronary stent coatings with special nanocomposite polymers whose biofunctionality can be enhanced by the integration of antibodies or peptides in the polymers (Tan et al. 2013). Another example is nanostructured probes for in vivo gene detection which can be used for cancer diagnosis (Guo 2010).

Corporate strategy

It has become accepted that new ventures are one of the main drivers of innovation in nascent technologies. However, due to the high development costs related to nanobiotech, new ventures often need financial backing from investors (e.g. venture capitalists) or a corporate venture arm of a large company. In turn, large companies typically use a mix of in-house R&D and mergers and acquisitions (M&A[18]) to obtain additional technological capabilities. Rather than focusing entirely on in-house R&D, large firms are shifting considerable R&D efforts to small innovative firms – typically new ventures. It can be advantageous for large firms to use their financial resources to purchase small companies based on the technological achievements of the targeted company. For small companies, it means that successful innovation makes them attractive acquisition targets and provides them with more bargaining power to drive up the potential purchase price, particularly if there is evidence of proof of concept or first market successes. This is an important motivation for small firms to continue to emphasize R&D (Phillips and Zhdanov 2012).

Large pharmaceutical companies concerned about their current competitive position and the industry trends, need continuously to feed their new product pipeline and to increase their presence in the neighboring growth areas of biotech (Haacker et al. 2013) and nanotech. Established companies frequently supplement their knowhow and product portfolios by acquiring new ventures with the desired technological capabilities (Maine et al. 2014). Current biotech companies can move towards the interdisciplinary nanobiotech area by purchasing counterparts with complementary competences in the nanotech sector – and, vice versa, current nanotech can shift towards the nanobiotech intersection. Companies that are already operating in the nanobiotech area can strengthen their expertise by acquiring additional capabilities in either technology area through M&A.

Eating and being eaten

Whereas the existence and rise of nanobiotech and approaches for knowledge integration are well documented (Maine et al. 2014; Wang and Shapira 2012; Takeda et al. 2009; No and Park 2010), less is known about the origins of nanobiotech from an economic perspective. For example, how do established companies respond to the industry evolution? What is the role of startups and what business and R&D strategy should they pursue? Since the early 2000s, various studies on nanobiotech – especially those related to scientific advancements, patents or citation data - have perhaps created the impression that nanobiotech is already economically important. But is this perception supported by empirical evidence?

Analyzing M&A data might hint at industry trends and at technological areas where companies search for additional assets – particularly in the case of technology-intensive and highly uncertain industry sectors such as nanobiotech. In the case of a surge towards nanobiotech, this would be mirrored in M&A

[18] In a merger the acquired company ceases to exist whereas in an acquisition the acquired company continues to exist as a subsidiary.

data. The analysis aims to elucidate the formation of the nanobiotech industry, drawing on management ‘make or buy’ decisions: generally, firms enter the nanobiotech arena either by extending their R&D to the related subjects and/or by acquiring companies with the respective competencies.

This longitudinal analysis of M&A activities is based on Thomson Reuters Eikon data for the time period 2005-2014. In line with Maine et al. (2014) this paper adopts a global focus on firms targeting human healthcare, with both nanotech and biotech capabilities. By systematically matching M&A data and patent data for individual companies, the author identified 596 individual M&A events during the period 2005-2014 where both technological disciplines were present. Further details on the research method are described in the ***Supplementary Information***.

Nanobiotech only by-catches in mega deals?

Overall, a macro-perspective on M&A activities reveals that the annual number of deals and the total volume of M&A transactions affecting nanobiotech moves on a relatively stable level (**Figure 1**). The development is indicative of a coalescence of the nanotech and biotech worlds. Most noticeable in the development of the total purchase amounts is the drop around the year 2012, probably due to a delayed effect of the financial market turmoil in preceding years. However, over time, total transaction amounts do not show an increasing trend and the results contradict the perception of a rush towards nanobiotech.

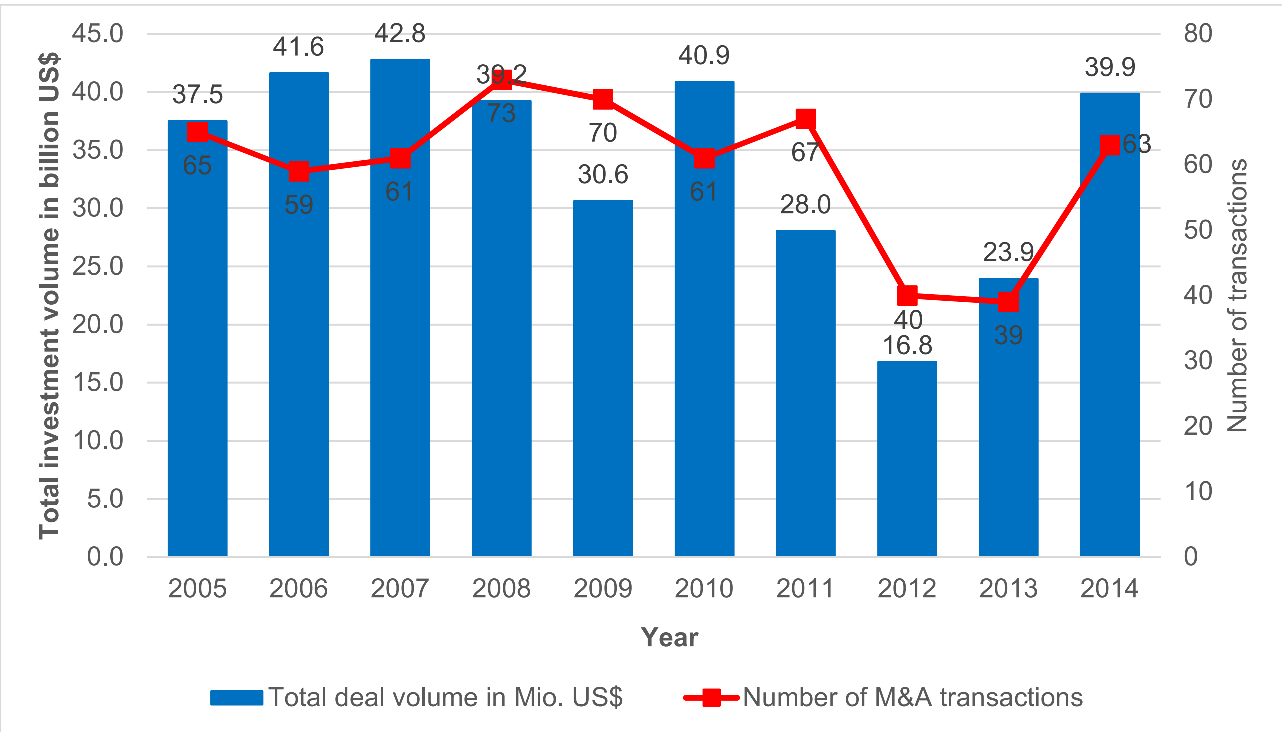

Figure 1: Total number and volume of M&A transactions per year

Source: Thomson Reuters Eikon data retrieve.

The generally high level of M&A investment volumes show that established companies spend considerable amounts of money on enhancing product portfolios and feeding their R&D pipelines. However, it remains unclear as to what fraction of each single purchase price is attributable to the nanobiotech area. In particular, for the larger pharmaceutical deals, the acquirers' motivations for the payments are more likely to be grounded in the traditional pharmaceutical business based on small-molecule chemical compounds, with nanobiotech playing a subordinate role. Considering the contribution of nanobiotech products to total revenue for some pharmaceutical groups (**Table 1**), the results indicate that nanobiotech is at an early stage and represents only a relatively small part of the total healthcare business.

The results put the economic significance of nanobiotech into perspective and the M&A data do not suggest a surge towards nanobiotech. Nonetheless, nanobiotech embodies significant future growth potential. The Compounded Annual Growth Rate (CAGR) of nanobiotech in market forecasts (Research and Markets 2014; BCC Research LLC 2014) frequently exceeds 10% for the time period up to 2020, and the market is expected to grow to about US$200 billion by that same year (Grand View Research 2014).

Where the heart is beating

From the geographical distribution of M&A transactions, it becomes apparent that most are geographically concentrated in a few countries (**Figure 2**). The United States accounts for the biggest number of M&A transactions and the highest total transaction volume. Between 2005 and 2014, companies headquartered in the United States invested some US$161.8 billion to acquire nanobiotech competences from around world. In the same time period, companies around the world spent around US$220.6 billion on acquiring United States based target companies. Europe is ranked second for global M&A transactions completed between 2005 and 2014. Most notably, Switzerland (which is home to the large (bio)pharmaceutical companies Roche and Novartis) is the European leader for M&A investment volume related to nanobiotech. Over the period analysed, Swiss companies invested more than US$37.8 billion to expand their nanobiotech portfolios. At the same time, Switzerland accounted for US$23.7 billion for the purchase of companies across the world. Germany is ranked third; German companies spent around US$34.7 billion on M&A while the amount spent on acquisitions of German companies was US$15.2 billion.

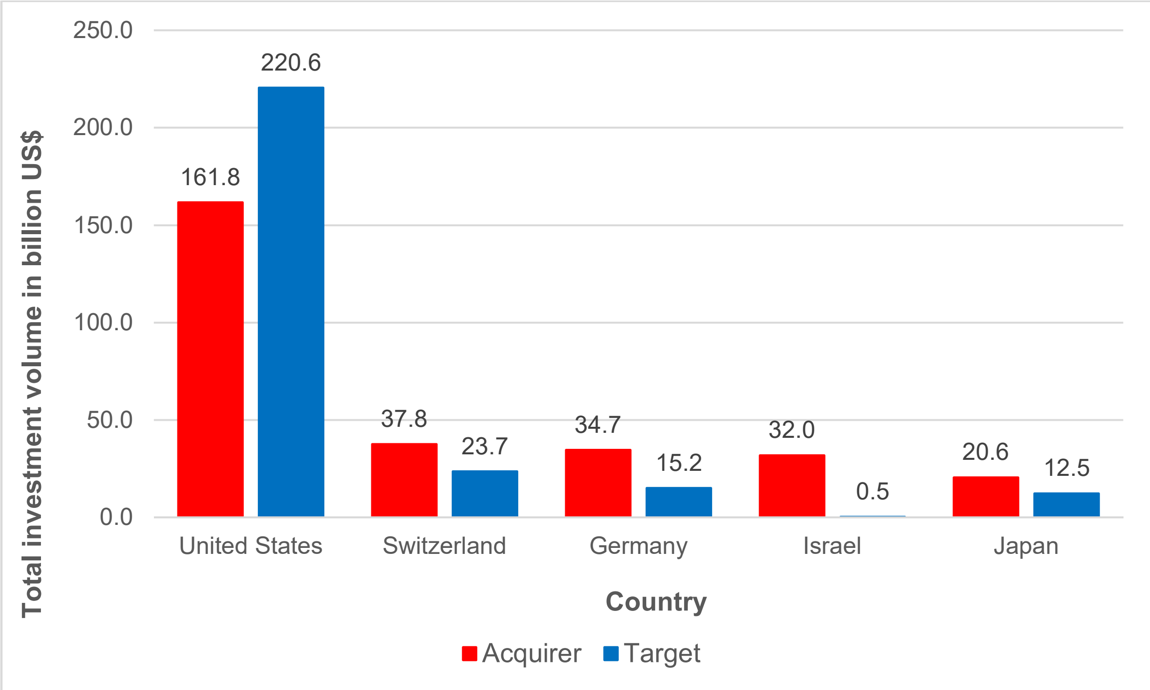

Figure 2: Total M&A investment volume between 2005-2014 distributed by the headquarter country of the acquirer and target firm (Top 5 acquirer countries)

The red coloured ('Acquirer') bars in the chart illustrate the total amount that companies headquartered in the respective country invested globally to acquire nanobiotech capabilities ('where the money comes from'). The blue coloured ('Target') bars illustrate the total amount that has been invested to acquire nanobiotech companies in the specific country, regardless whether by domestic or foreign acquirer companies ('where the money goes to').

Source: Thomson Reuters Eikon data retrieve.

Lagging R&D expenditure by acquirers

One alternative to capturing additional technologies through M&A is to acquire them via in-house R&D. Our analysis reveals another development beyond nanobiotech: over time, R&D expenditures by established companies has increased relatively less than revenues and profits. Between 2005 and 2014, average annual R&D expenditure of acquirer companies (respectively of their parent companies) increased from US$610 million to US$989 million, an increase of 62%. This moderate rise in R&D expenditure is sobering in the context of the simultaneous developments on the income side. Over the same period, on average, the total annual revenues rose to US$5.9 billion in 2014, a 66% improvement on 2005 figures and despite the small economic slowdown in 2014 (**Figure 3**). The divergence between R&D expenses and total revenue indicates that established companies prefer acquire knowhow through external sources, for example through M&A transactions, rather than investing in in-house R&D. In other words, the relative increase on the revenue side is not accompanied by a proportional increase in R&D expenses, which seems to be in line with the observations by other authors (e.g. Phillips and Zhdanov 2012; Cha et al. 2015) that larger companies prefer to "outsource" R&D to small ventures and reap the rewards through M&A, rather than increasing their own R&D. The consideration of the profit developments of the acquirer – typically larger companies – provides an even clearer picture: over the last ten years, acquirer companies have witnessed an increase in EBITDA[19], which has been growing at an even faster rate than total revenue. On average, per acquirer company, EBITDA increased to US$2.3 billion in 2014, corresponding to an 80% increase on 2005 (**Figure 3**). Although, for some companies, the nanobiotech segment is only a minor division and accounts for a smaller portion of the amount, the widening gap between income and expenses suggests that acquirer companies had the ability, with additional funding, to further enhance their research labs. Instead, established companies seem to have placed more importance on other strategies, such as M&A, to capture the required technologies.

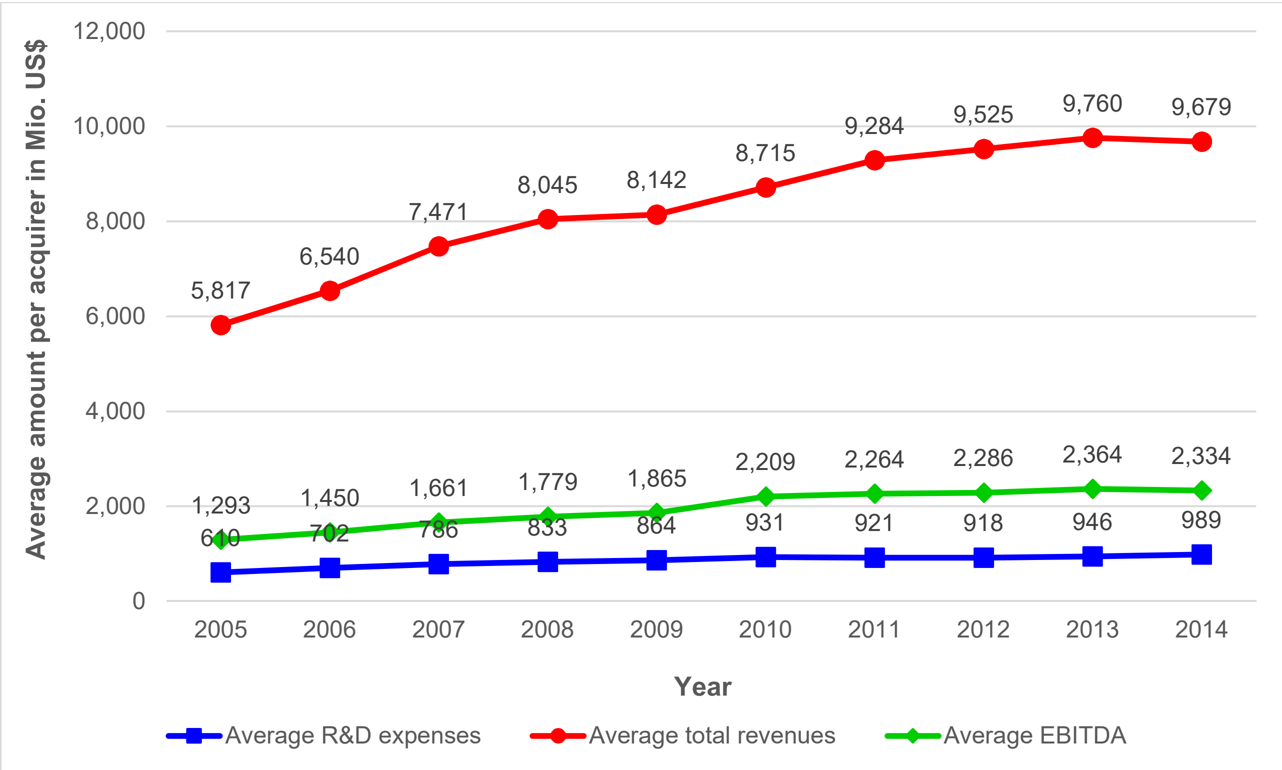

Figure 3: Key financial performance indicators of the acquirer companies.

Note: Each data point represents the annual average amount across acquirer companies in the examined company group.

Source: Thomson Reuters Eikon data retrieve.

19 Earnings before interest, taxes, depreciation and amortization (EBITDA) is a performance measure commonly used to compare profitability between companies and industries. The idea is that EBITDA provides a clearer picture of companies' operations than other performance measures as it eliminates differences in taxation and the effects of financing and accounting decisions.

Conclusion

To summarize, there continues to be an ongoing consolidation of nanobiotech industry firms via M&A activity. While nanobiotech represents considerable technological as well as commercial potential, from an economic perspective, it is at an early stage of its evolutionary trajectory. Similar to other technological areas, in the field of nanobiotech M&A are popular tools used to capture supplementary capabilities, while R&D expenditure by established acquirer companies is lagging. The results indicate that the lessons learned from other technology fields apply also to nanobiotech: While large, established companies focus on exploiting existing technologies, smaller companies focus on exploring new and uncertain technologies. In this context, engaging in an R&D "race" with small firms might be disadvantageous for large companies, which might be better off outsourcing their R&D to small firms and cherry picking via M&A if results are promising. For innovative startups the possibility of becoming an attractive acquisition target amplifies the potential gains from technological advancements and is an incentive to reinforce their in-house R&D efforts (Phillips and Zhdanov 2012). Since new ventures are a primary driver of technological innovation, nearly all biotech companies have established corporate venture arms (Huggett 2014) to allow exploitation of business opportunities.

Applying this to the nanobiotech area, the relatively stable level of M&A deals suggests that larger companies are still hesitant and let the small companies go ahead with exploring the highly uncertain technology field. Nevertheless, large firms sit on watch to reap the most promising advancements trough company acquisitions.

Considering the predominant role of the United States in the underlying technological areas – nanotech (OECD Directorate for Science Technology and Innovation 2014b) as well as biotech (OECD Directorate for Science Technology and Innovation 2014a) – it is not surprising that the United States is the leader in the nanobiotech sector - a situation that seems unlikely to change in the near future.

Product	Nanotech approach / agent	Indication	Company group[a]	Revenues by product 2014	Total revenues 2014	% of total revenues
Neulasta	Pegfilgrastim (PEG-rhGCSF)	Chemotherapy-induced (febrile) neutropenia	Amgen	4,596	20,063	22,9%
Abraxane	Paclitaxel protein bound nanoparticles	Cancer	Celgene	848[b]	7,670	11,1%
Xeplion	Nanocrystals	Schizophrenia	Johnson & Johnson	1,588	74,331	2,1%
Emend	Nanocrystalline aprepitant	Antiemetic	Merck & Co	553	42,237	1,3%
Pegintron	PEG-α-interferon 2b	Hepatitis C, chronic	Merck & Co	381	42,237	0,9%
Neoral	Nanoemulsion	Immunosuppressant, Prophylaxis of organ rejection following organ transplant	Novartis	684[b]	53,634	1,3%
Rapamune	Nanocrystalline sirolimus	Immunosuppressant	Pfizer	339	49,605	0,7%
Somavert	PEG-HGH antagonist	Acromegaly	Pfizer	229	49,605	0,5%
Pegasys	PEG-α-interferon 2a	Hepatitis C, chronic	Roche	1,115	47,744	2,3%
Mircera	Polymer-protein conjugates	Anemia, kidney failure, chronic	Roche	458	47,744	1,0%
Copaxone	Copolymer of alanine, lysine, glutamic acid and tyrosine	Multiple sclerosis	TEVA Pharmaceutical	4,237[b]	20,272	20,9%

Table 1: Examples of commercially available nanotherapeutic products.

Table 1 presents a selection of drug products for which specific revenue data were disclosed in the 2014 annual report of the company group. The listed company groups might hold commercial rights for other nanotherapeutic products not listed here, e.g., because of non-disclosure of financial data due to insignificant revenue amounts. [a]In the case that the market rights for the drug product is shared among several companies (or subsidiaries) or if the patent protection has expired, only one distributing company group is listed. [b]Net product sales.

Source: Own presentation based on previous studies (Wagner et al. 2006; Hafner et al. 2014) and 2014 annual report data.

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Paper 4: Supplementary Information

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Sourcing innovation through M&A: Lessons from nanobiotechnology

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The mergers and acquisitions (M&A) data presented in the longitudinal analysis are based on Thomson Reuters Eikon data for the time period 2005-2014. The paper builds on previous work by others (Maine et al. 2014; Paull et al. 2003) and focuses on global pharmaceuticals and medical research firms with both nanotech and biotech capabilities. It looks at M&A transactions, where both capabilities are present, regardless of which party –target or acquirer – brings which capabilities.

There are different combinations among M&A transactions where both capabilities are present (**Supplementary Table 1**): Firstly, on the target and acquirer sides there may be capabilities in only one of the underlying technology fields, and the transaction complements both areas and, thus, leads to the emergence of a nanobiotech company. Secondly, the acquirer company may have nanobiotech capabilities and wants to extend its expertise in either the nanotech or biotech field by purchasing a target company with the relevant expertise in the targeted field. Thirdly, a nanobiotech company may purchase another nanobiotech company. Fourthly, one party – target or acquirer – might possess expertise in nanobiotech while the other party may have had neither capability before the M&A event. This fourth possibility is not considered in the current paper because data collection is based on M&A reports where either target or acquirer company is classified as a biotech (or pharmaceutical) company. In the first three possibilities, an M&A brings together both technology areas and expands the nanobiotech capabilities in the resulting business entity.

No.	Target's capabilities	Acquirer's capabilities
1a	Biotech	Nanotech
1b	Nanotech	Biotech
2a	Biotech	Nanobiotech
2b	Nanotech	Nanobiotech
3	Nanobiotech	Nanobiotech
4a	Nanobiotech	-
4b	-	Nanobiotech

Supplementary Table 1: Possible distribution of the relevant capabilities until the M&A transaction

Cases 4a and 4b are beyond the scope of this investigation and are excluded by the chosen research design. The focus here is on M&A transactions that lead to increased nanobiotech capabilities for the resulting business unit(s).

The considerable expertise of many multinational pharmaceutical companies in the areas of biotech and nanotech, often exceeds that of dedicated biotech or nanotech companies. However, the former typically are classified as pharmaceutical companies according to most industry classification standards. Thus, it was decided to include pharmaceutical firms in the analysis.

Research Method

The data collection process involved four consecutive steps:

1. Filtering the complete Thomson Reuters Eikon database for M&A transactions where either the target or acquirer company was labelled a biotech or pharmaceutical company. The time period for the analysis was 2005 to 2014. Compared to the biotech and pharmaceutical industries Thomson Reuters Business Classification (TRBC) and most other industry classification standards do not have a separate industry class for nanotech. This leads to the next step.
2. In order to identify those M&A transactions where, in addition to biotech or pharmaceutical capabilities, nanotech capabilities were involved, firm names were used to run a patent data search. Utilitzing the world patent database Derwent Innovations Index (DII) the author searched for patent data for the companies involved in the M&A transactions. Since individual patents are assigned to one or more patent classes, the author used the patent class label of each patent to identify companies with expertise in the areas of nanotech, (medical) biotech or both. By systematically scanning each company's patent portfolio for certain patent classes (Derwent Manual Codes).[20] related to the nanotech area, the author identified 356 companies which have or had at least one nanotech patent. Based on the filter criteria in step 1, biotech capabilities are present for each M&A transaction in this examination.
3. Applying the DII patent information to the M&A database, the author identified 1,154 individual M&A transactions over the 10 years 2005-2014, where both capabilities were present, irrespective of which party brought them–target, acquirer or one of the ultimate parent companies. Based on the original data retrieved in step 1, either target or acquirer company is related to the biotech or pharmaceutical industry.

[20] Derwent Manual Codes (DMC) are assigned to patents by DII indexers. The DMC system classifies patents based on their technological application and from a rather economic perspective, whereas there are other classification systems that are based on the patent's technological background. Furthermore, the DMC system is more specific than other classification systems such as the International Patent Class (IPC) Codes or the Derwent Class Code.

4. To avoid the misleading influence of mega pharmaceutical M&A transactions in which nanobiotech plays only an insignificant role, the author excluded 16 transactions where transaction volumes exceeded US$10 billion. Also, as the financial terms of the transaction were disclosed for only 598 of the remaining deals, the final sample is constituted of these 598 M&A.

To verify the existence of both sets of capabilities in the examined M&A transactions and in cases where the data analysis revealed uncertainties about a company's nanobiotech expertise (e.g. in the case of several different companies with the same firm name), the author drew on a systematic internet search, e.g., on company webpages, press releases and analysts' reports. Financial performance data were retrieved from Thomson Reuters Eikon for the acquirer companies in the M&A transactions.

The data collection process began in October 2014 for the time period 2005-2013 and numbers for the reference year 2014 were added in early 2015. Initial results were scrutinized and refined via feedback from 11 nanobiotech experts including academic scientists, founders and CEOs of start-ups, IP experts, and M&A professionals who checked the preliminary results to provide more detailed insights into the nascent nanobiotech industry.

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Paper 5

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Commercializing nanobiotech: Time to take stock

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Much ado about nothing! That is what several observers think about the integration of novel techniques from the area of nanotech into biotech, that is, about nanobiotech. While developments in scientific research in the field of nanobiotechnologies have led many to believe we were on the verge of a new revolution in life sciences, evidence of actual market impact is scant (Bosetti and Vereeck 2011; Maine et al. 2014). In other words, substantial promise on the upside potential, in both economic as well as social terms, but under delivery in terms of real impact.

The main argument in this paper is that while there is some truth in this, it should be acknowledged that we are at the beginning of a new technological cycle and there are signs that this cycle eventually will ramp up. In fact, initial development in the biotech field, now an established reality, was also characterized by cycles of high expectation frenzies, followed by a sober and slower implementation process (e.g. Pisano 2006; Mazzola 2003; Paull et al. 2003).

Three factors enabled the biotech industry to fulfil its promise (Pisano 2006): a vibrant process of transfer of scientific findings from academia to industry through academic spin-offs; the presence of a well-developed, willing VC industry capable of providing funding at an early, technically highly uncertain stage; and the development of a market for know-how enabling new ventures to interact profitably with established organizations (Orsenigo et al. 2001). At the core of each of these three pre-conditions for take-off, was the presence of a well-developed entrepreneurial environment which sustained experimentation through new ventures. In biotech, Genentech and few other early movers became the catalysts that sparked both a new industry and an organizational model that allowed new entrants to cooperate and compete with both established organizations (Orsenigo et al. 2001; Henderson et al. 1999; Arora et al. 2001) and academic departments. A similar model for the nanobiotech industry has yet to emerge although the premises for it exist.

Who dares to take the first step?

Large pharma companies continue to be somewhat reluctant to embrace nanobiotech fully because of the veil of uncertainty that shrouds it. On the one hand, they are wary about the cannibalization of old competences and products. On the other hand, so far there is no evidence of a revolutionary product driven by the integration of nanotech with biotech. Hence, these firms possibly perceive that in betting on nanobiotech they may lose out in their familiar territory while seeing no prospects of making a discovery that would change the course of the field and their economic performance.

In most cases nanobiotech has been applied to improve the technical effectiveness of existing product attributes (**Figure 1**). Especially in the *therapeutic* area, some applications have benefitted from the integration of specific nanobiotech features such as targeted drug delivery based on liposomes or polymers. However, numerous cutting edge innovations in the therapeutic area, such as 'smart pills', are at a very early stage – particularly in terms of clinical trials and regulatory approval (Martin 2015). Despite the large number of publications highlighting scientific advancements, the distance between publication and demonstration of clinical effectiveness (not to mention market entry) is very long. In the context of medical *diagnostics*, nanoparticulate formulations are used as a contrast agent for imaging purposes. However, there is a limited number of imaging applications where use of (intravenously administered) nanoparticulate-based formulations lead to evidently better medical decision bases compared to standard low-molecular-weight diagnostics (Rizzo et al. 2013). Thus, it is important to distinguish among different types of nanobiotech applications because, at present, they differ vastly in terms of both stage of advancement and underlying skills and capabilities.

In contrast, biotech companies had the example of Genentech. The adoption of recombinant DNA technology enabled the manufacture of synthetic human insulin which took the place of insulin of animal origin (e.g. from cows and pigs). This success convinced the industry of the enormous potential of biotech. However, a similar successful case has still to emerge for nanobiotech.

In addition, there is uncertainty for firms over regulation. The fluid regulatory regimes designed to monitor developments based on biotechnologies, impinge differently on different nanobiotech application areas, often generating bottlenecks (e.g. in diagnostics), while simultaneously failing to take adequate account of the peculiarities of nanobiotech products. For instance, in September 2015, the first application for regulatory approval of a 'smart pill' - a pill with an ingestible sensor which would provide information on medication patterns - was accepted by the United States Food and Drug Administration (US FDA) (Proteus Digital Health 2015). In contrast, basic and applied research are several steps ahead and sensors and electronics for controlled drug delivery have been available for some time (Martin 2015). Although the US FDA recently issued guidelines on the regulation of nanotechnology products (U.S. Food and Drug Administration 2015), the tensions between the latest technical advancements and the regulatory frameworks are working to slow development processes, generate uncertainty and foster public discourse on nanobiotech inspired more by fear than by understanding (Bosetti and Vereeck 2011).

Alongside these aspects of profound uncertainty, there are positive signs of progress, including a number technological results with broad commercial applicability (**Figure 1**), and there are the financial resources to exploit it.

Significance of the nanotech component	Diagnostics	Therapeutics
Enabler of entirely new products or applications	• Graphene-based biosensor devices (Kostarelos and Novoselov 2014), e.g. photodetectors (Koppens et al. 2014) • Next generation DNA sequencing	• Body-on-a-chip devices used to recreate and control biochemical pathways of human and animal bodies (currently in vitro) (Gordonov et al. 2014) • Coating technologies for drug-eluting coronary stents (Helmus 2006) • Nanoparticles assisted gene transfers
Modification of existing products or applications	*Imaging (in vitro and in vivo)* • Engineered nanoparticles used as contrast agents to amplify magnetic resonance signals (Mi et al. 2016) or ultrasound signals (Borden and Sirsi 2014)	*Drug delivery technologies, e.g.* • Nanoparticles and DNA-origami (Douglas et al. 2012) structures used as drug carrier and for controlled/targeted drug release • 'smart pills' integrating an ingestible sensor to record medication patterns or for the controlled release of pharmaceuticals (Martin 2015)

Medical area

Figure 1: Selected nanobiotech products and applications.

Where is nanobiotech positioned in the general nanotechnology patenting landscape?

To investigate future commercialization we need to start by looking at the current patenting landscape. The analysis in this paper makes it clear that a full assessment of the economic potential of nanobiotech cannot be based only on its medical applications.

In general, patenting activity in relation to nanotech has surged since the mid 2000s, spiking in 2011 (**Figure 2**). Doubtless, universities are a major driver of this rush as they are increasingly enhancing their patenting activities in their pursuit for income from licensing and academic spinouts.

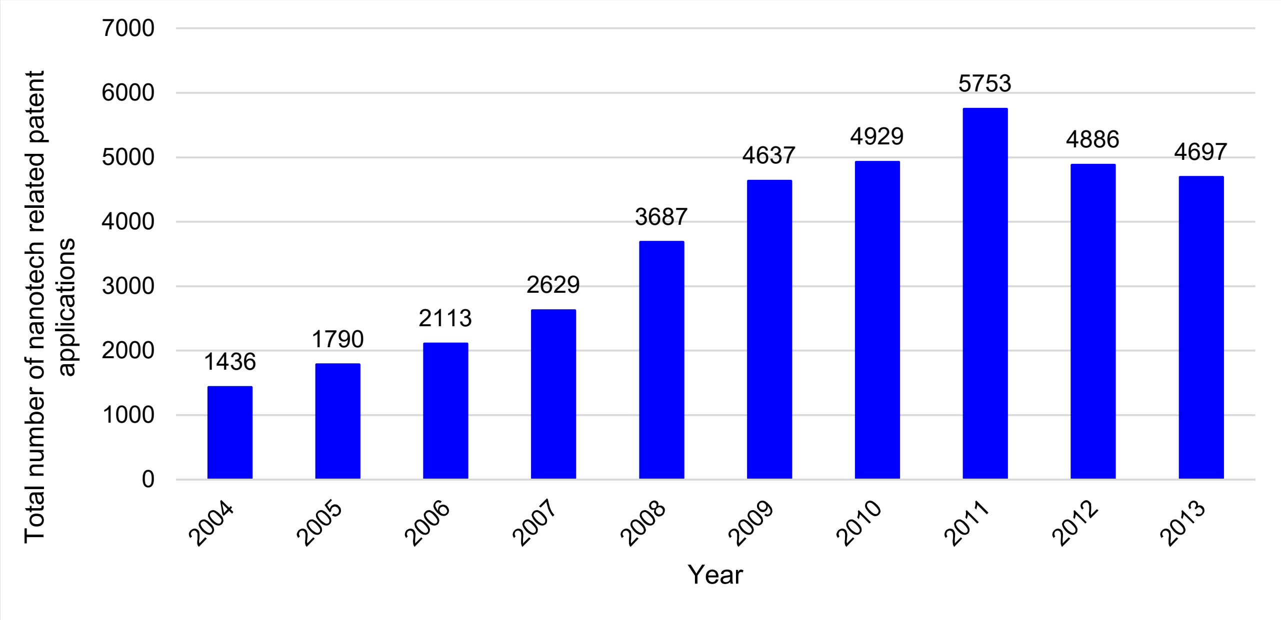

Figure 2: Global number of nanotech related patent families by year.

Note: Classification by year is based on priority application date. In this study nanotech related patents are those patent (families) assigned to IPC subclasses B82B and/or B82Y.

Source: Derwent Innovations Index.

To better understand the potential significance of nanobiotech, the methodology employed here draws on an approach used in a OECD study of emerging technologies (OECD 2013). Analyzing the technological classification codes of nanotech patents and considering with which other codes nanotech most frequently (co-)occurs, enables identification and ranking of technology areas in which nanotech applications are most often being integrated. Data were retrieved on 44,410 nanotech related patents (IPC subclasses B82B and B82Y) from the global patent database, Derwent Innovations Index, in March 2016. Based on this dataset of patents with a nanotechnology label, the top20 co-developments were identified by ranking pairs of 4-digit IPC classes occurring in the patent documents. The patent priority application date enabled clustering of co-occurrences for two five-year time periods: 2004-2008 and 2009-2013.

Analysis of patent classifications reveals that there are some other technology sectors, such as chemistry or electronics, which are more frequently combined with nanotech than with medical science (**Figure 3**). This finding highlights the versatility of nanotech. Although its impact on medical products and applications may not (yet) be extensive, nanotech has gained considerable importance in relation to healthcare, and integration of specific nanotech methods into the medical sector has increased substantially in recent years. This is perhaps an indication that, despite the emphasis on applications of nanobiotech to particular topics (**Figure 1**), any discussion of nanobiotech might better be framed in terms of nanobiotech as a '*general purpose technology*' (GPT) (Youtie et al. 2008). GPTs describe a scientific developments with multiple, pervasive application across a variety of technical areas (more similar to, e.g., semiconductors than recombinant RNA techniques).

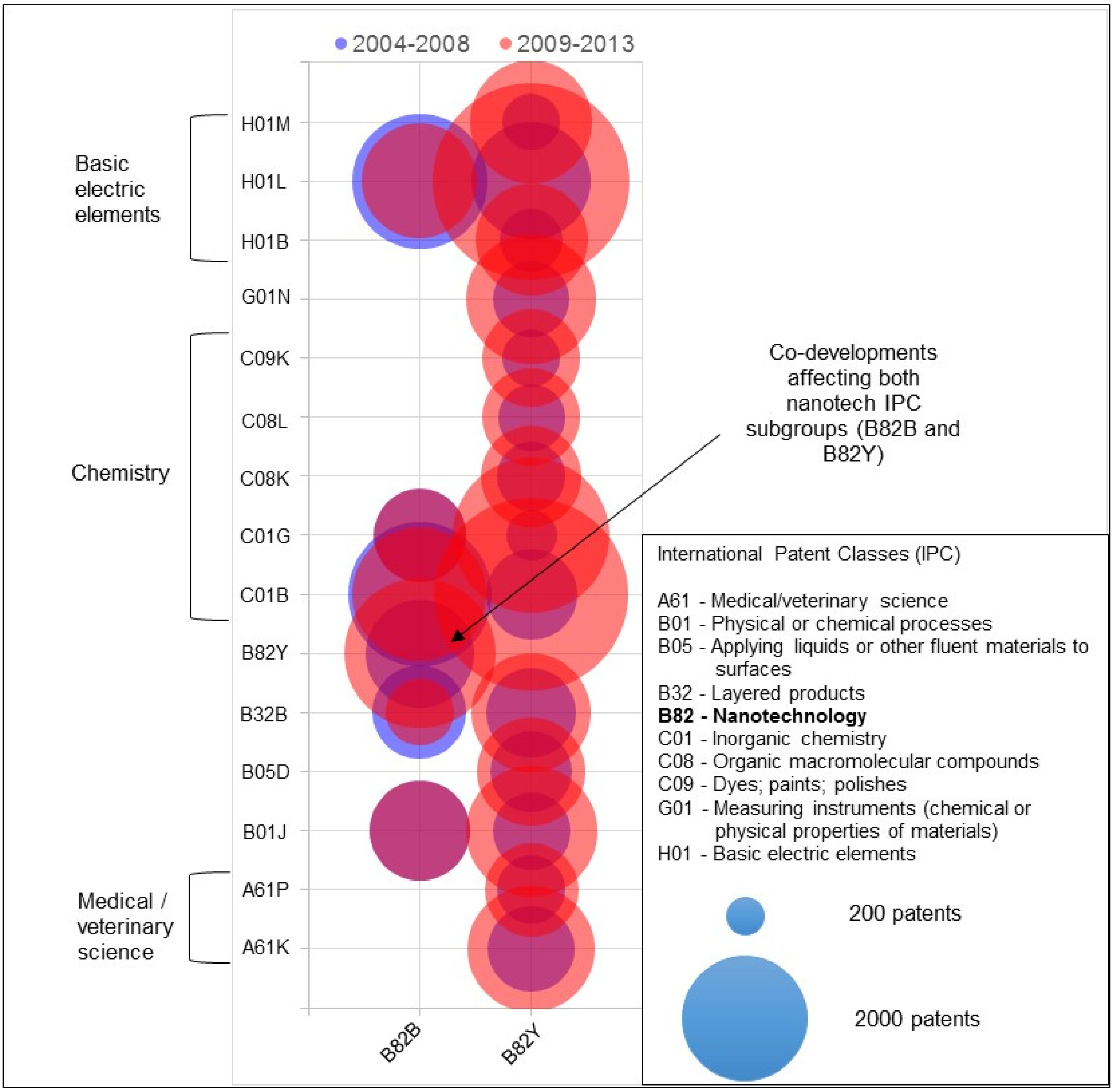

Figure 3: Co-development of nanotech related patent technologies in big pharma: top 20 IPC class co-occurrences (2004-2013).

Note: The number of co-developed patents between two IPC classes is illustrated by a bubble at the intersection between the respective x- and y-axes. Co-development combinations that have *increased* in number over time are represented by red bubbles which are bigger than the blue bubbles in the same location. *Decreasing* numbers of co-developments are represented by blue bubbles which are bigger than the red bubbles in the same location. The technologies experiencing the highest boom in co-developments with nanotech are in the field of basic electric elements (particularly electric semiconductor devices H01L) and the area of inorganic chemistry (especially non-metallic chemical elements C01B). Nanotech appears to be relatively rarely in the area of medical sciences (IPC class A61).

Source: Derwent Innovations Index.

The long gestation cycles of GPTs have been well documented and universities have to experiment very broadly to identify a first set of successful applications that will generate and sustain the interest of VCs and established organization. At the same time, the wide potential and commercial applicability of GPTs makes them increasingly appealing to large firms.

Love (of science) or money? Analysing VC investments in nanobiotech

Significant amounts of government funding have been devoted to nanobiotech research by academic institutions, which is reflected in the increasing number of academic nanobiotech patents. However, the private sector has yet to adapt to advancements in nanobiotech research. So, what needs to change?

Samila and Sorenson (2010) point to the strong interaction between private financial intermediation and public research funding for promoting entrepreneurship. In particular, they show that public funding of academic research and venture capital are complementary for fostering the creation of new firms: venture capital plays a pivotal role in transforming public funding into tangible commercial results. This applies particularly to the case of nanobiotech where the translation of research results into commercial products and applications can be a very capital-intensive and lengthy R&D process, exacerbated by the extensive regulatory approval process. Particularly in the pharmaceutical (therapeutic) context, the associated expenditures are opposed to uncertain outcomes due to the technological difficulties and persistently low clinical success rates magnify these issues (Calcoen et al. 2015; Hay et al. 2014).

The VC industry has been a central source of financing for nascent technologies such as biotechnology. Once Genentech showcased the great commercial potential of biotech and attracted the attention of (potential) investors and corporate decision-makers (Henderson et al. 1999), VC became the engine of technological progress and commercialization of research discoveries in the medical biotech sector (Huggett 2016; von Krogh et al. 2012; Morrison and Lahteenmaki 2015). But what is the attitude of investors towards nanobiotech? In this context, comparison of VC investments allocated to traditional biotech companies versus those allocated to nanobiotech companies provides interesting insights.

To examine the financing situation for nanobiotech compared to traditional/pure biotech companies, we collected funding data from the global life sciences VC database 'Biotechgate' (http://www.biotechgate.com), and systematically matched these investment data to patent data from Thomson Reuters Derwent Innovations Index (http://thomsonreuters.com/). Based on the priority application date of company patents, this matching allowed us to link companies' individual IP portfolios to investment amounts. As result of this matching, we identified a total of 188 investment rounds between 2007 and 2014 where the target company had already filed patents from both strands, nanotech and biotech ('nanobiotech'). The matching also yielded another 1,701 financing rounds where, at the date of financing (irrespective of any patents from other technology areas; see **Supplementary Information** on the methods online), the target firm had filed only biotech patents.

The data analysis shows that starting in 2009 investors gradually came to recognize nanobiotech as an attractive investment target. Globally, *total annual investment amounts* more than tripled, from US$189 million in 2009 to US$625 million in 2013 (**Figure 4a**).

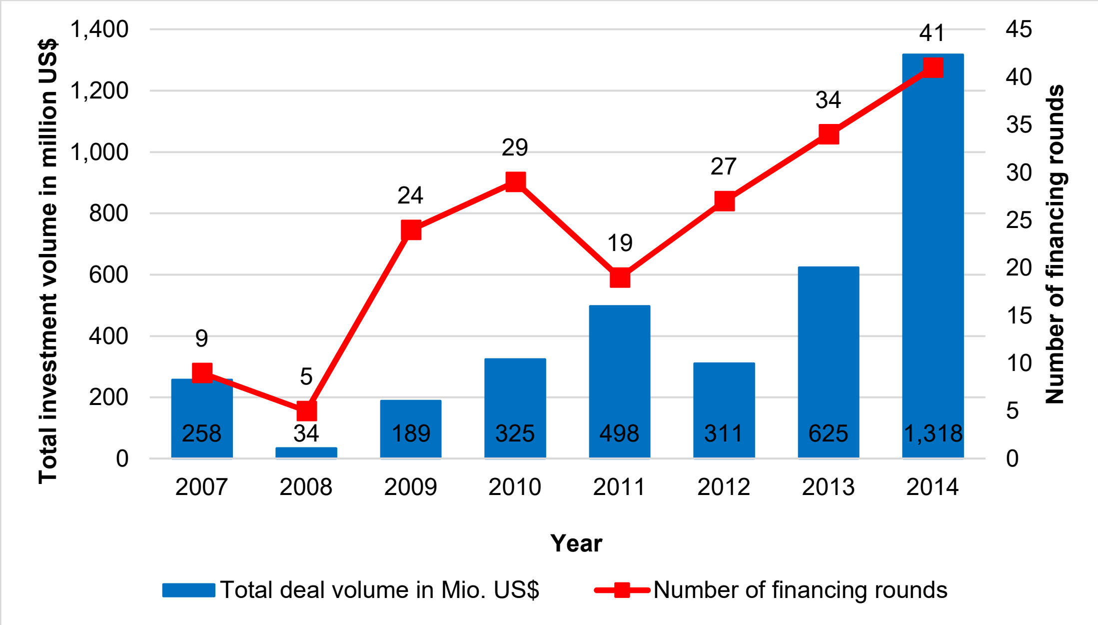

Figure 4a: Nanobiotech companies

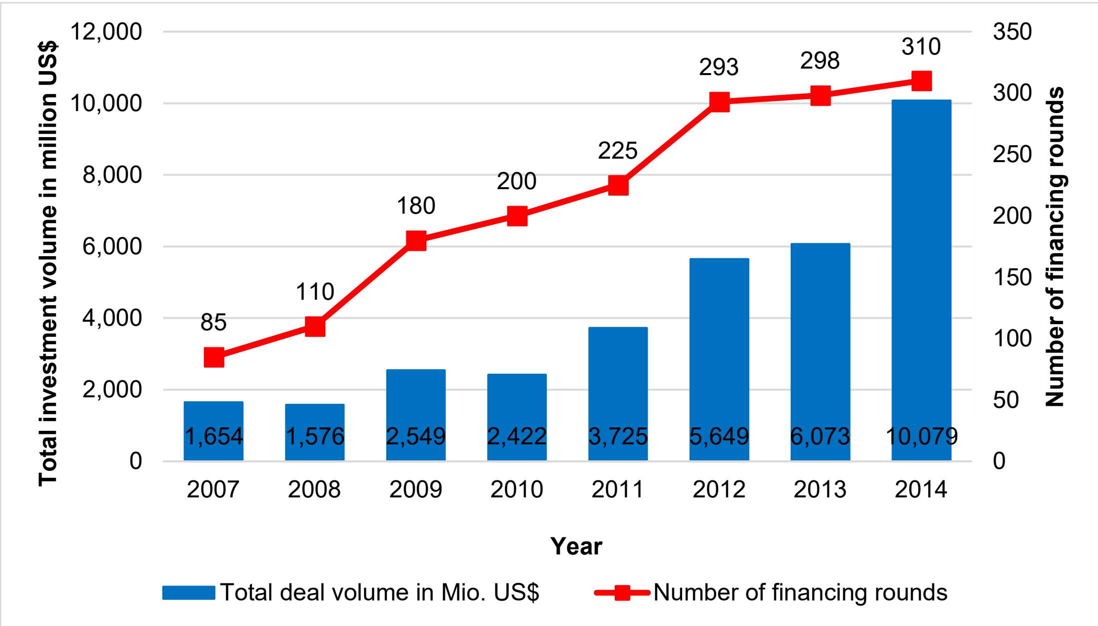

Figure 4b: Biotech companies

Figure 4: Total number and volume of financing rounds per year for (a) nanobiotech companies, (b) biotech companies

Note: For in the context of this analysis, nanobiotech companies are companies that possess both nanotech and biotech patents, irrespective of ownership of patents from any other technology areas. Biotech companies are firms that possess biotech, but not nanotech patents, irrespective of ownership of patents from some other technology area.

Source: Biotechgate.

Growth in this four year period, corresponds to a compounded annual growth rate of ~35%; in 2014, 41 financing *rounds* were assigned to nanobiotech firms, the highest number in the eight year period analysed. These 41 financing rounds represented a total amount of more than US$1.3 billion – a leap of 111% over 2013 figures. In line with this surge in total deal volume, the average funding amount increased from US$7.9 million in 2009, to over US$18.4 million in 2013, and to US$32.1 million in 2014.

The increasing number and volume of capital investments in nanobiotech suggests increasing interest from corporate VC and other investors in nanobiotech and suggests increased momentum of its commercialization some 15 years after the launch of the first big nanotech research initiatives in the United States (Paull et al. 2003). It is striking that the development of investments in nanobiotech companies mirrors investments *in (pure) biotech* firms. Although nanobiotech received only some 10% of overall investment in traditional biotech (**Figure 4b**), average investment per nanobiotech firm is comparable.

Similarly, there are some clear parallels between nanobiotech and biotech in the *sources* of financing (**Figure 5**); they differ in the proportion of companies making it to IPO stage which is relatively lower for nanobiotech.

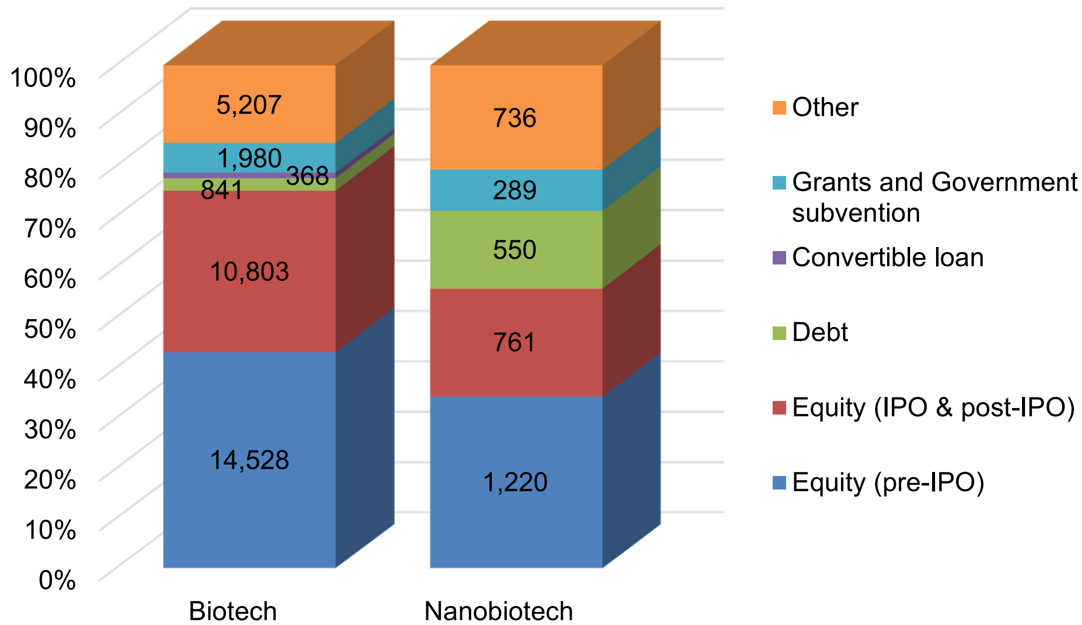

Figure 5: Decomposition of investments 2007-2014 by sources in percent of the total investment amount (y-axis) and in absolute million US$ amounts (inside base numbers)

Note: For the purpose of this analysis, *nanobiotech companies* are those companies that possess both nanotech and biotech patents, irrespective of any patents from any other technology areas. *Biotech companies* are firms that possess biotech patents but no nanotech patents, irrespective of any patents from any other technology areas.

Source: Biotechgate.

The larger percentage of debt financing among the group of nanobiotech companies compared to their biotech counterparts is due mainly to a US$450 million debt capital injection to Theravance (South San Francisco, CA, USA), supporting a strategic separation process. However, this US$450 million raised by Theravance in April 2014, was an exceptional windfall. Apart from this outlier, **Figure 5** depicts the financing structure between biotech and nanotech as quite similar. However, analysis of financial sources does not explain the significant differences in absolute financing levels (**Figure 4a** versus **4b**). A possible explanation for this might be the number of companies active in the two fields and, thus, the number of investment opportunities. For the United States, OECD (OECD Directorate for Science Technology and Innovation 2015a) counted 11,367 companies active in biotech in 2013 versus 10,341 firms active in the wider nanotech area (OECD Directorate for Science Technology and Innovation 2015b). The idea that the intersection - the nanobiotech company universe - is significantly smaller compared to (traditional) biotech is exemplified by our dataset; a total of 188 investment rounds for nanobiotech was distributed among only 56 recipient companies; for comparison, the 1'701 investment rounds in biotech relate to a total number of 737 recipient companies in our life sciences VC database.

While the results suggest that the number of companies active at the interface between nanotech and biotech remains relatively small,[21] the presence of an active life sciences VC market suggests potential growth. Nonetheless, one problem related to nanobiotech is that most domain experts with profound understanding of both nanotech and biotech are academics. As result, there is a shortage of people experienced in identifying and pursuing business opportunities – on the entrepreneurial/corporate side as well as on the investor side (Paull et al. 2003). In the same vein, the opportunities opened up by nanoscale engineering might be out of sight of some investors – particularly generalist investors. However, for some specialist investors, nanobiotech is an attractive opportunity to leverage their expert knowledge and to beat general investors to the punch.

Conclusion

Academic research institutions have achieved major advancements in nanobiotech research, as evidenced by the proliferation of scientific publications on this area. However, discussion of its economic impact remains based on conjecture. Nanobiotech may not always produce groundbreaking products or applications (**Figure 1**). Yet, its potential lies in the breadth of its potential application. And, commercial exploitation is in its infancy but is currently getting off the ground. Compared to the early days of biotech, nanobiotech can be described as in a pre-Genentech phase. We lack a clear, accepted, highly visible example (Freeman et al. 2001) of successful commercialization. Recent developments based on VC investments, typically the enablers of new technology areas and key indicators of future technological trends, suggest that the commercialization of nanobiotech is gaining momentum (**Figure 4a**). Developments in investment for nanobiotech mirror investment in the traditional biotech area – although of smaller dimension in the former case.

The groundwork for the path to the development of nanobiotech is being laid by universities. The author affiliations on published nanotech research show that most nanobiotech domain experts are working in

[21] Other authors (e.g. Maine et al. 2014) find that the number of nanobiotech related firms has grown since the early 2000s.

academia and may not be practised in bringing their discoveries to market (Paull et al. 2003). Universities need to educate and motivate young talents to pursue the commercialization of their research results. Universities are central for translating scientific advances into social and economic value: in the nanobiotech domain universities own the intellectual property rights and host researchers and inventors with scientific insight in this new technology field. A closer connection between academic scientists and the private sector is needed to achieve more effective translation of basic research to marketable applications. For instance, *secondments* of academic researchers to the R&D departments of private companies would expand academics' horizons to include the business/entrepreneurial world and could contribute also to a smoother transition of the new technology including the underlying (tacit) knowledge. Furthermore, a stronger emphasis in universities on *translational research* (Pisano 2006) would speed the passage of basic research results towards applied R&D and make it easier for the private sector to take over.

Contributions

S.B., P.F., and G.V. contributed equally as second authors to the concept, design, execution and analysis of all data and manuscript writing.

Competing financial interests

P.F. is CEO of Venture Valuation, Zurich, Switzerland.

M.W., S.B., and G.V. declare no competing financial interests.

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Paper 5: Supplementary Information

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Commercializing nanobiotech: Time to take stock

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I. Research method to Figures 2a, 2b, 3 in the main article

To examine the financing situation for nanobiotech small and medium sized enterprises (SMEs) compared to traditional/pure biotech companies, we collected financing data from the global life science VC database 'Biotechgate' (http://www.biotechgate.com) and matched these investment data systematically to patent data from 'Derwent Innovations Index' (Thomson Reuters). Based on the priority application date of the companies' patents, the matching revealed the relationship between the IP portfolio (at date of investment) and the investment amount.

As result of this matching, we identified a total number of 188 investment rounds (56 recipient companies) between 2007 and 2014 where the target company had already filed patents from both strands, nanotech and biotech and is considered a 'nanobiotech' firm, and another 1,701 financing rounds (737 recipient companies) where the target firm had filed only biotech patents at the date of financing (irrespective of any patents from any other technology area). To mitigate potential biases arising from different company ages in the biotech vs. the nanobiotech group, we included only companies/transactions with target companies aged less than 15 years. This is in line with the focus on young technology firms in the investment analysis.

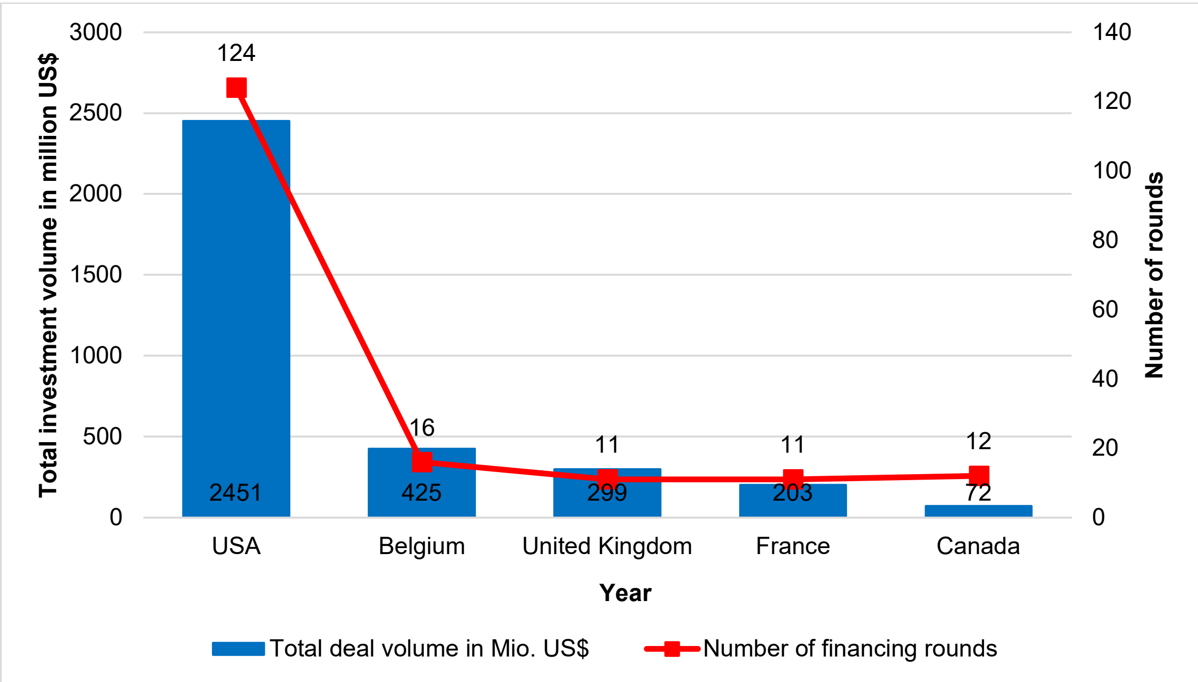
In the context of this analysis, *nanobiotech companies* are companies owning both nanotech and biotech patents, irrespective of patents from any other technology area. *Biotech companies* are firms possessing biotech but not nanotech patents, irrespective of patents from any other technology area.

II. Additional Analyses

Supplementing the empirical results in the main paper, this section provides further insights into the evolution and economic significance of nanobiotech today. The data provided by the Biotechgate VC database (2007-2014) allows a more nuanced understanding of the types of life sciences being funded, based on the geographical location of the recipient firms' headquarters, technical subsectors, type of financing and age of companies receiving VC financing.

1. Geographical Split

Disaggregating investments in 2007-2014 by geographical region, **Supplementary Figure S1** shows that the majority of recipient companies are headquartered in the United States. The relatively low number and total volume of VC investments in Europe-based firms (2007-2014) indicates that entrepreneurial activities and commercialization of nanobiotech is significantly lower in Europe.



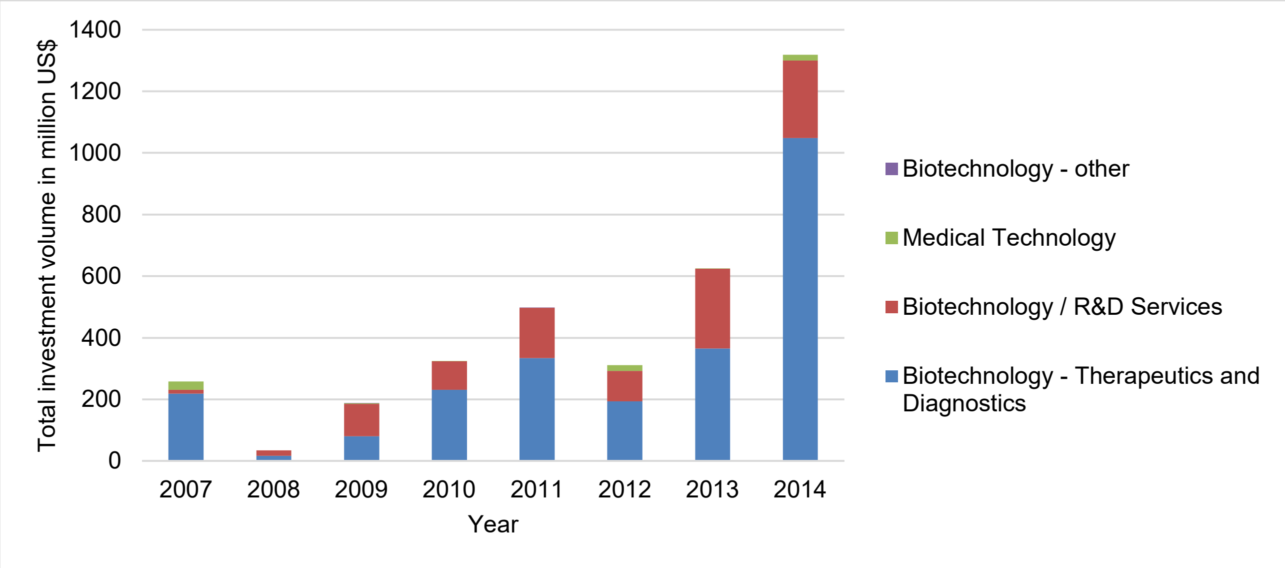
Supplementary Figure S1: Total number of financing rounds to nanobiotech companies by country (aggregated numbers 2007-2014; Top5 countries).

Note: This figure is based on the same sample as Figure 4a in the main article document.

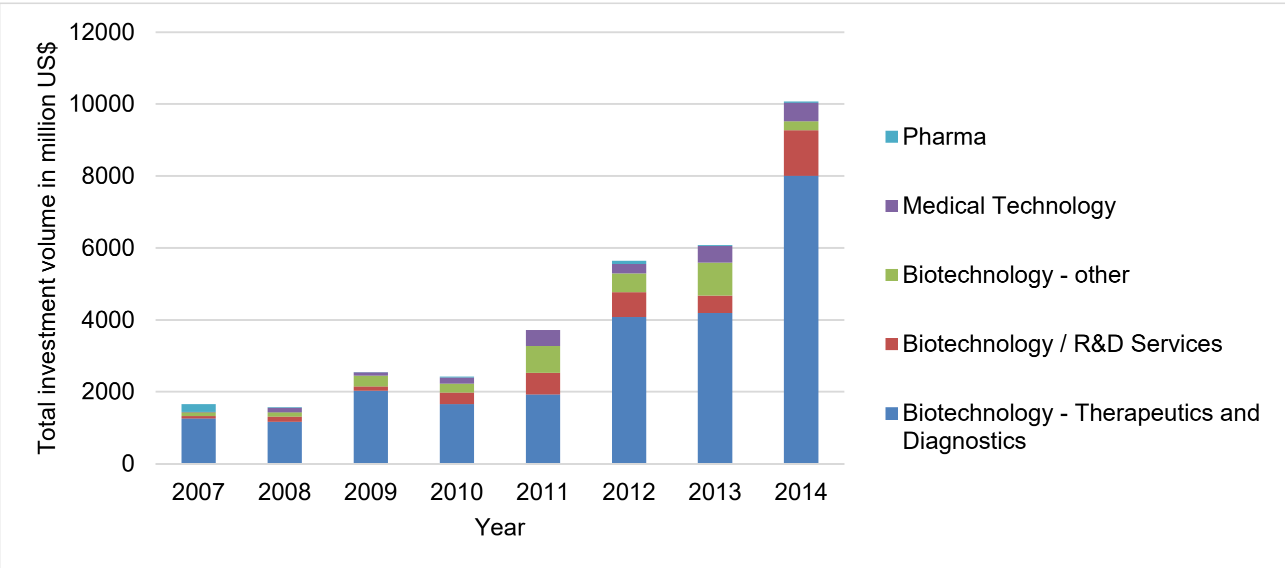
Source: Biotechtgate.

2. Sectoral split

Splitting our life science VC database by technological subareas shows that the field of *Biotechnology-Therapeutics and Diagnostics* (see definitions in **Box 1**) attracted the most interest from VC investors in 2007-2014. The predominance of this field applies to both (traditional) biotech and to nanobiotech (**Supplementary Figure S2a & S2b**). However, despite similar capital allocations in these areas, nanobiotech accounts for only one tenth of the funding volume assigned to biotech.



Supplementary Figure S2a: Nanobiotech companies.



Supplementary Figure S2b: Biotech companies.

Supplementary Figure S2: Total number and volume of financing rounds per year for (a) nanobiotech companies, (b) biotech companies.

Source: Biotechgate.

Technology sector definitions

Companies categorized as **Biotechnology-Therapeutics and Diagnostics** are firms whose core business is application of biotechnology to discovery and development of novel therapeutic compounds and probe molecules for medicine.

Companies in the **Biotechnology / R&D Services** category provide support services, such as product development services, analytical services, screening, contract manufacturing and contract R&D, to the biotechnology industry.

Companies categorized as **Biotechnology - Other** apply the concepts of biotechnology (using living organisms or biological substances for the development of products and services) to areas other than drug development for medical use. Examples of areas covered under biotechnology-other include Agrobio companies, cosmetics companies, environmental companies, food technology companies, industrial biotechnology companies, nutraceutical companies and veterinary companies.

Pharmaceutical companies are commercial enterprises that research, develop, produce and sell drugs and other medicines. In today's economy these enterprises are usually large companies that deal in both branded and generic compounds and rely, at least partially, on smaller biotechnology companies for in-licensing of novel compounds for their pipelines.

Medical technology companies are involved in research, development, production and marketing of systems and devices for medical applications for humans and animals.

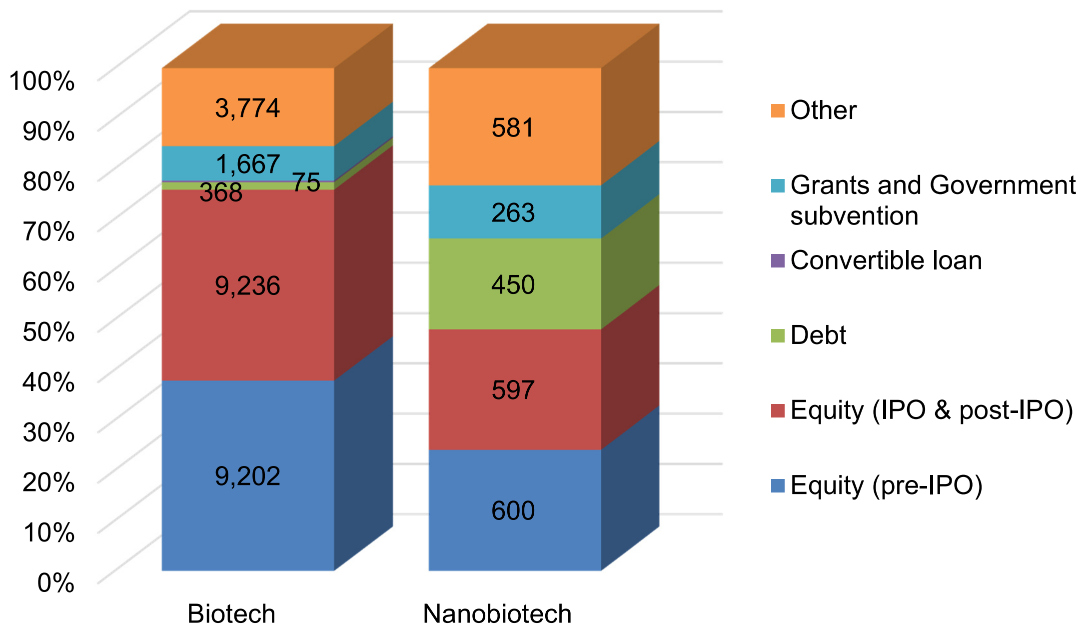
The **investor** category includes all types of financing sources for life sciences companies. These include bank funds, public funds, venture capital funds, business angels, corporate investors, institutional investors, private investors and foundations.

Supplementary Box S1: Technology sector definitions.

Source: Biotechgate website (last accessed 3 October 2016). Further definition details are available at http://www.biotechgate.com/web/cms/index.php/covered_industry_sectors.html

3. *VC investment by stage of development (focus on Biotechnology - Therapeutics and Diagnostics)*

Stage of companies at time of financing provides another perspective on VCs' investment preferences (2007-2014). While **Supplementary Figure S2** indicates that investors have a strong preference for the *Biotechnology - Therapeutics and Diagnostics* sector, **Supplementary Figure S3** splits the investment amounts for that subarea by type of funding. Specifically, the percentage of equity investments is significantly higher (≈ 75.8% for pre-IPO and IPO & post IPO together) for biotech companies compared to financing allocated to nanobiotech companies (≈ 48.0% for pre-IPO and IPO & post IPO together). Although the nanobiotech industry is considerably smaller in absolute number, relative comparison of financing structures suggests that nanobiotech depends stronger on funding from debt and government donors rather than equity investors.



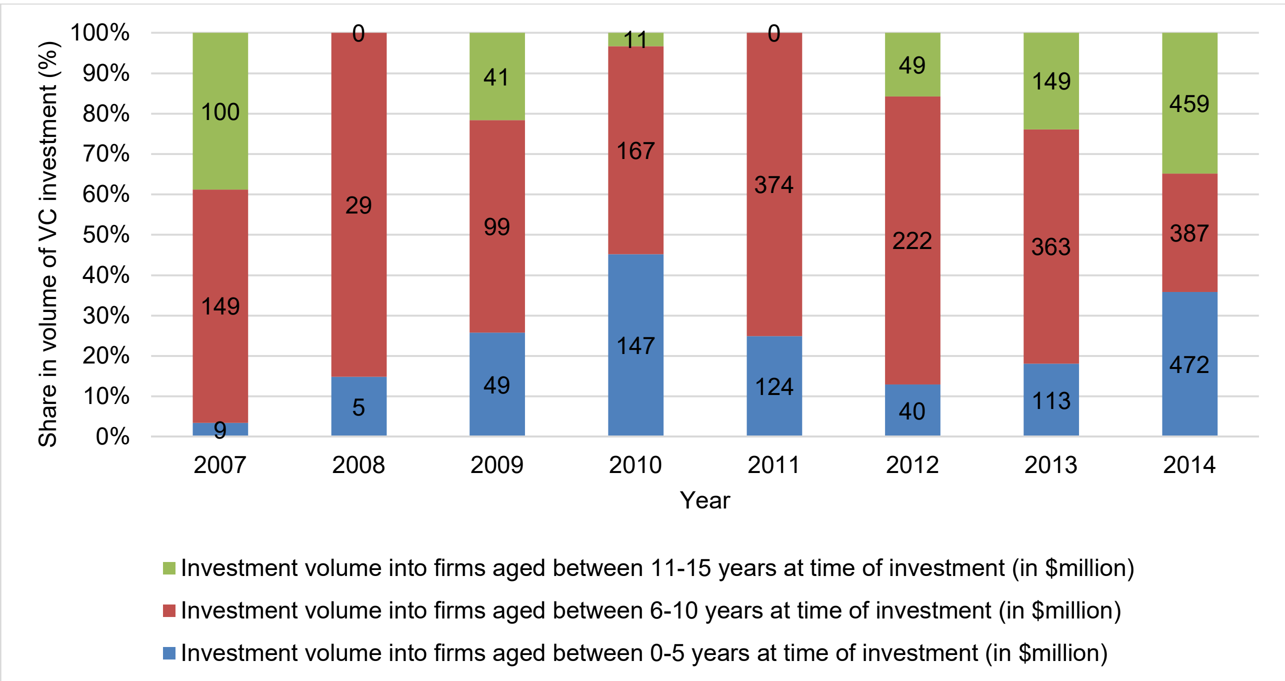
Supplementary Figure S3: Decomposition of investments 2007-2014 into the life science subsector ***Biotechnology - Therapeutics and Diagnostics*** by sources as a percentage of the total investment amount (y-axis) and in absolute US$ millions (inside base numbers).

Source: Biotechgate.

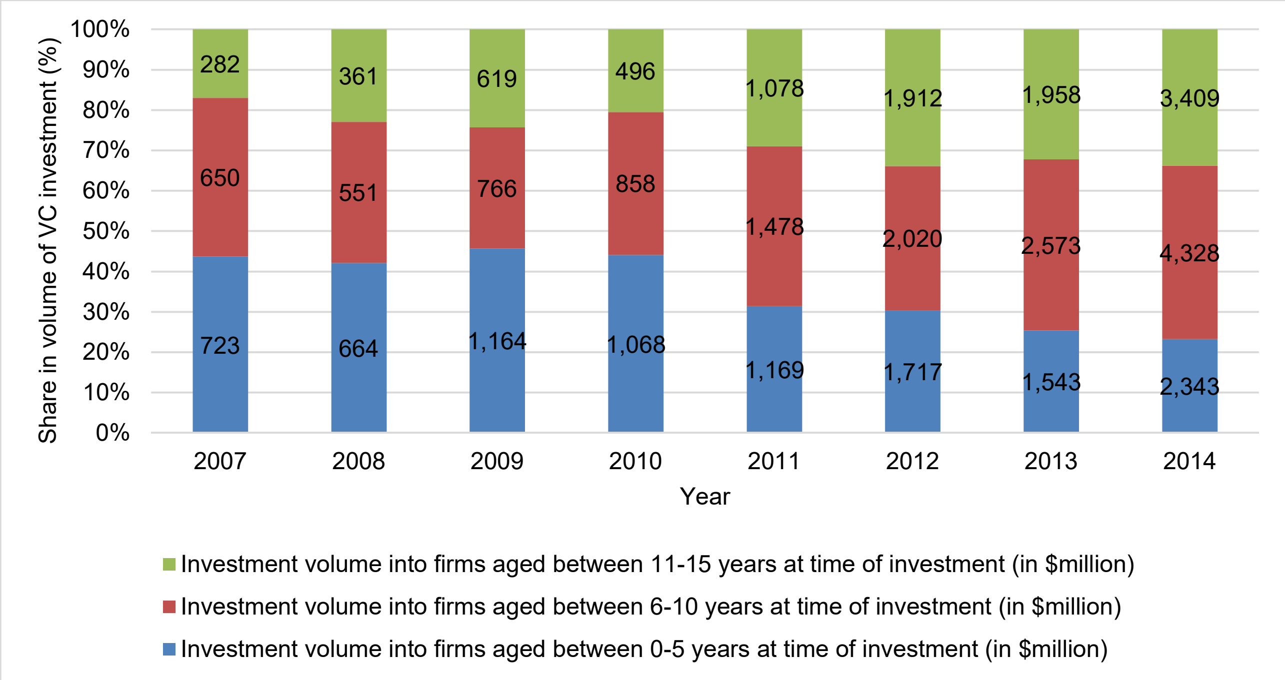
4. VC investment by target company age

Extending the analysis by company stage in the previous section, analysis of VC investment by target companies' age shows again that nanobiotech is a relatively new technology and most companies active in the field are less than 11 years old. While a fairly stable proportion of funding is assigned to biotech companies that are older than 10 years (**Supplementary Figure S4b**), nanobiotech funding is dominated by companies aged between 6 and 10 years (**Supplementary Figure S4a**). Only since 2012 has the proportion of funding allocated to firms aged 6-10 years been continuously decreasing with higher amounts going to younger companies (<5 years in age at the time of the financing) or firms aged 11-15 years (in the meanwhile).

To conclude, the results suggest that VC is an important source of finding for early-stage nanobiotech companies, many of which are still active and have matured. The results support observations of the biotech industry, which has witnessed a surge of financing for research-intensive early stage ventures (Huggett 2016; 2015). In the search for returns in a highly competitive environment with generally low levels of interest rates, investors are seeking out young nanobiotechnology startups.



Supplementary Figure S4a: Nanobiotech companies.



Supplementary Figure S4b: Biotech companies.

Supplementary Figure S4: VC investment by age of the target company for (a) nanobiotech companies, (b) biotech companies

Source: Biotechgate.

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