The Production and Public Dissemination of Scientific Knowledge in University-Industry Projects

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Table of Contents

Preface

This dissertation was written from September 2016 to May 2021 at the Danish Centre for Studies in Research and Research Policy (CFA), Aarhus University. Being a PhD student and producing a dissertation over such a long period has been an extreme challenge and a great experience. Fortunately, I have been among people who have made challenges easier to overcome and who have made the experiences greater and memorable. I owe these people a great deal of gratitude.

First and foremost, I am grateful to my supervisor team, Professor Carter Bloch and Professor Jesper Schneider. Carter and Jesper have been a part of my research project from the very beginning. I am thankful for their support, thorough comments, a high level of patience, and qualified advice.

In the spring of 2018, I was fortunate enough to be able to visit the buzzing and inspiring environment at Ingenio, UPV in Valencia. A special thanks to Adrian, Pablo, Richard, and Anna for making me feel welcome and for providing useful feedback and inputs that significantly pushed my research forward.

I started at the centre as a student assistant in 2013 and soon will have worked at the centre for nine years. In almost all of these years, I have had one colleague who has been extremely helpful and enjoyable to be around. A special thanks to Emil for helping with numerous tasks and for the long talks about both our fields and many great laughs.

I would also like to highlight the fantastic people at CFA and the PhD group. I am thankful to all my colleagues for being inspiring and the effort they put into being great colleagues both professionally and socially. A special thanks to Emil, Ea, Mathilde, Lise, and Massimo for going beyond what is to be expected of a colleague. Additionally, the senior researchers at the centre deserve praise. In particular, I would like to thank to Mads, Ebbe, Kaare, Jens Peter, and Niels for always having an open door and open mind. I would also like to thank the many colleagues who came and went during my PhD and who have left a lasting impression due to their humor and friendliness. Thank you for the laughs, inspiring discussions, and input to Asger, Astrid, Sigurd, Anders, Mathias, Sanne, Heidi, Rachel and Lea. I would also like to extend my utmost gratitude to Jane. Jane deserves a medal; she is always willing to lend a hand and is a wonderful person to be around.

On a personal level, I am certain that the long and winding road of a PhD would not have been possible for me to complete if not for the love and support from my family. I owe a great deal to my parents and siblings. Thank you for being supportive, loving and fun. Finally, I want to thank Rikke for your patience, making my life easier, more enjoyable, and for being my own personal cheerleader when I needed it the most. You are the best and you and Olivia mean the world to me.

Aarhus, September 2021
Thomas Kjeldager Ryan

Chapter 1: Introduction

1.1 Consequences of university-industry interaction for academic research

It is generally understood that academic research contributes to industrial innovation and economic development (Cohen, Nelson, & Walsh, 2002; Dominique Foray & Francesco Lissoni, 2010; Mansfield, 1991; Mowery, 1998; P. E. Stephan, 1996). An often-highlighted channel of this contribution is university-industry collaboration. The expected benefits to economic growth and innovation of university-industry collaboration has motivated policy-makers to promote and incentivize interaction between the university sector and private business. In Denmark, research and innovation policy has focused on promoting and facilitating interaction between academics and firms, with the expectation that such interaction will provide both economic and scientific benefits (Aagaard, 2012). Under the headline “from research to invoice”, reforms of the Danish university system have been designed to foster collaboration between universities and the public and private sector as well as commercialization activities within the university sector (ibid). During the 2000s, as in other countries, Danish universities established technology transfer offices, while a new legal framework encouraged universities to engage in commercial exploitation of innovations created by their employees. The aim of the legislation is to ensure that research results produced with the support of public funds are made useful to the Danish society through industrial utilization ("Bekendtgørelse af lov om opfindelser ved offentlige forskningsinstitutioner," 1999). On behest of the government a yearly commercialization report, named “from knowledge to growth”, documents Danish universities’ activity with regards to technology transfer, patenting and collaboration. *The report aims to contribute to creating the foundation to evaluate whether the collective effort of public-private collaboration is adequate and has the largest possible effect (Styrelsen for Forskning og Innovation, 2016, p. 6 [Authors translation]).*

The political consensus is that more interaction is not only beneficial to the economy but also to scientific “excellence” (Styrelsen for Forskning og Innovation, 2015, p. 5). While empirical evidence of the importance of public research for innovation is well-established (Mansfield, 1998; Nelson, 2004; Salter & Martin, 2001), it is less established how and to what degree academic research and the public dissemination of scientific knowledge is affected within university-industry collaborations. There are conflicting views on how university-industry collaboration may affect academic research. On one hand, scholars argue that engagement with industry is generally conducive and complimentary to traditional academic research activities (D'Este, Tang, Mahdi, Neely, & Sanchez-Barrioluengo, 2013; Markus Perkmann, Salandra, Tartari, McKelvey, & Hughes, 2021; M. Perkmann, Tartari, McKelvey, Autio, Broström, et al., 2013). A number of studies have shown a positive correlation between publication output and commercialization activities (Larsen, 2011; Van Looy, Callaert, & Debackere, 2006), which has been interpreted as an indication that engagement with industry is complimentary to academic knowledge production (for an example of such an interpretation see M. Perkmann and Walsh (2009, p. 1036)). Moreover, scholars argued that even when collaborations with firms do not lead directly to the production and publication of scientific knowledge, they provide academics with learning benefits and access to resources that benefit the pursuit of future research (Markus Perkmann et al., 2021; M. Perkmann & Walsh, 2009). On the other hand, critical voices argue that interaction with industry may influence both the direction and focus of academic research and that relevant research outcomes may be kept from the public due to the commercial interests of industrial partners (Behrens & Gray, 2001; Florida, 1999; Krimsky, 1999; Slaughter & Leslie, 2001).

The present dissertation aims to understand how the direction of academic research and the dissemination and impact of scientific knowledge is affected within the context of university-industry projects. The dissertation provides an empirical and conceptual basis to discuss whether the focus on promoting interaction between academics and firms may have unintended or negative consequences for scientific knowledge production. The present chapter introduces the dissertation work by explaining the background of the research problem, the research objectives, and the structure of the dissertation.

1.2 Background

While university-industry collaboration is not a new phenomenon, the Interaction between academics and firms has become increasingly commonplace throughout academia. Academics engage directly with firms through consulting, collaborative research and development (R&D). In 2019, Danish universities entered into more than 2000 collaborative agreements in which one or more private actors were involved (*Tal om danske universiteter 2019*, 2020). These include large publicly funded research projects, co-funded research, clinical trials, contracted research as well as industrial PhD and Postdoc projects. This of course only captures the formalized collaborative interactions between university academics and firms. Between 1995 and 2013, the number of publications co-authored between academics and firms in Denmark nearly quadrupled. In 2013, public-private co-authored publications accounted for approximately 11 % of total publications published with an author based in Denmark (Bloch, 2017).

Interaction between university academics and firms is supported by the funding structure of science. Block funding for university research is decreasing, consequently the ability to attract competitive funding from public and private sources is important for university academics. Meanwhile, in many countries legislation and public funding of research is designed to promote university-industry collaboration (Mowery & Sampat, 2004; P. E. Stephan, 2008). For example, in Denmark a range of funding programs have the primary aim to fund research and development projects with participation of both academics and firms (Aagaard, 2012). Universities are expected to and increasingly take on the role of contributing to and stimulating economic development (Foss & Gibson, 2015). A prevalent logic behind science and innovation policy is that increasing interaction among key actors in national innovation systems (Lundvall, 2016) may create more innovation and economic growth. The increase in direct interactions between academia and industry has also been interpreted as an indication of a new mode of knowledge production or change in the social contract of science (Gibbons, 2000).

On top of the economic argument, policymakers and scholars alike have argued that direct interaction between university and industry contributes to the advancement of scientific research as well (D'Este & Perkmann, 2011; De Fuentes & Dutrénit, 2012; Garcia, Araújo, Mascarini, Santos, & Costa, 2020; Schaeffer, Ruffoni, & Puffal, 2015; Tartari & Breschi, 2012). Including firms in the academic research process is argued to contribute to more societally relevant research and provides academics access to a wealth of empirical knowledge, specialized assets and research problems, which can lead to novel research outcomes (D'Este & Perkmann, 2011; Dutrenit, De Fuentes, & Torres, 2010).

However, the interaction between academics and firms may also have unfavorable or undesirable consequences for academic research and the development of scientific knowledge (Behrens & Gray, 2001; Slaughter & Leslie, 2001). Industry participation in the research process may affect the academic problem choice and thus the direction of academic research. Moreover, industry participation may lead to conflicts of interest, increased secrecy or selective publishing of knowledge claims because firms may lose potential rents from publication of academic knowledge claims that may be commercially relevant

(Crespo & Dridi, 2007; M. Perkmann & Walsh, 2009; P. E. Stephan, 2008). In the long-run, interaction with industry may lead to less open academic culture limiting the stock of available scientific knowledge. Additionally, firms may steer academics and academic research towards short-term application-oriented focus at the expense of fundamental long-term research (Behrens & Gray, 2001; Florida, 1999). In short, concerns are raised that what is good for business may not always be good for science.

Empirical studies show that academics who receive funding from industry on average publish a similar or higher number of publications compared to their peers (Goldfarb, 2008; Grimpe & Hussinger, 2013; Gulbrandsen & Smeby, 2005). However, a high degree of funding from industry and engagement in consultancy has been found to correlate with a lower level of publication output (Hottenrott & Thorwarth, 2011). Similarly, academics who report receiving industry funding have been found on average to publish research that is more frequently highly cited (Hottenrott & Lawson, 2017). However, the scientific impact of the research specifically produced with industry have not consistently been shown to be higher nor lower than publications from purely academic research (Godin & Gingras, 2000; Lebeau, Laframboise, Larivière, & Gingras, 2008). Academics who collaborate with industry tend to be more oriented towards application-oriented fields of research (Gulbrandsen & Smeby, 2005). Yet, there is limited evidence to whether the research they produce in interactions with firms differs from their research portfolio in general. The current understanding of engaged academics indicates that at least on average collaborating with industry does not negatively affect academics overall ability to produce and publish relevant research, nor is there any systematic evidence of a skewing of academics' research focus (Markus Perkmann et al., 2021; Van Looy et al., 2006). Empirical research has focused primarily on the average effects of industry engagement on academics' research production. However, this focus does not allow an investigation of when and for which types of interaction industry participation may influence impact and dissemination. There are indications that the project characteristics are related to the type of knowledge outcomes, whether they are published in academic literature, and the impact of published knowledge outcomes (Hottenrott & Lawson, 2017; M. Perkmann & Walsh, 2009)

Certain types of projects may be directly conducive to academic research and scientific knowledge production while others are not. For example, Perkmann and Walsh (2009) argue that collaborative projects focused on "knowledge generation" are likely to lead to scientific publications, while commercially oriented projects are less likely to lead to relevant scientific findings. However, when commercially focused projects do lead to academically relevant findings, publishing is less likely due to collaborating firms' appropriation concerns. However, there is limited empirical evidence of the extent to which the objective of collaborative projects and academic publication is related. Moreover, the objective of a project is often related to factors that may be relevant for the production and dissemination of scientific knowledge.

It has been argued that projects with firm participation may lead to more application-oriented outcomes and short-term focus than purely academic research (Behrens & Gray, 2001; Slaughter & Leslie, 2001). Therefore, academics involved in such projects may produce research that is more applied than what they otherwise pursue. Yet, we also know that academics that define their research as applied are more likely to engage in projects. Therefore, whether and to what extent engaging with firms in research projects pulls, pushes or skews academics towards new areas of research is still an open question.

1.3 Problem statement

The current understanding of how and to what extent university-industry collaboration influences the impact of academic research, the research direction of academic knowledge production and to what extent different types of university-industry projects relate to knowledge dissemination is limited. Through an examination journal publications in Denmark and university-industry projects in a Danish University, this dissertation aims to answer the following main research question:

- How is the production and public dissemination[1] of scientific knowledge[2] affected by the participation of industry in academic research[3]?

Overall, this thesis contributes with novel empirical findings and conceptual contributions related to the relationship between university-industry collaboration and scientific impact of scientific knowledge outcomes, the relationship

[1] *Dissemination* in this dissertation is directly related to the written communication of research findings or knowledge claims in scientific literature. Although I recognize that dissemination can include a much broader range of activities. The closely related concept, *disclosure* refers to the revealing of information in any way to the surrounding environment.

[2] *Scientific knowledge* is knowledge, which is produced using scientific methods. And, can be produced by both academic and industrial researchers.

[3] *Academic research* is the process of producing scientific knowledge by individuals or teams affiliated to universities and research organizations (as opposed to industrial research, which is performed in a private setting and does not necessarily involve scientific methods).

between university-industry collaboration and the direction of academic research, as well as the relationship between university-industry collaboration and the dissemination of knowledge.

Chapter 2 provides background information and definitions and elaborates on the research area and research questions by outlining the empirical and theoretical literature with regards to the question of direction, impact and dissemination of knowledge in the context of university-industry projects. Chapter 3 describes the approach of the dissertation and provides an overview of the empirical and theoretical chapters that make up the central part of the dissertation, as well as how each chapter approaches the posed research questions posed. Moreover, the chapter describes the central data sources and curation hereof.

Based on bibliometric analyses of Danish publication data, as well as qualitative and quantitative analyses of a set of university-industry projects at the University of Aarhus, the dissertation examines the following four sub research questions (RQ).

- RQ1.a: How is the decision to publish knowledge outcomes in university-industry projects determined?
- RQ1.b To what degree do university-industry projects lead to dissemination of knowledge outcomes in academic literature, and does the propensity to publish relate to specific project characteristics or the type of project?

The purpose of RQ1.a and RQ1.b is in part to understand which factors are relevant for deciding whether or not to publish knowledge outcomes from university-industry projects in scientific literatures, as well as to investigate to what degree university-industry projects lead to scientific outputs, and to what extent the project objective relates to the dissemination of knowledge.

Current knowledge highlights the scientific and commercial relevance of knowledge outcomes as the determining factor for whether university-industry projects lead to the public dissemination of knowledge (D'Este & Perkmann, 2011; M. Perkmann & Walsh, 2009). However, the theoretical understanding of how partners reach a decision of publishing or secrecy[4] is underdeveloped. Moreover, empirical research has yet to provide quantitative estimates on the relationship between project objectives and outcomes, as well as explore other relevant factors that may influence dissemination decisions.

[4] *Secrecy* is the active or passive behaviour of withholding and protecting knowledge so other actors may not gain access to it.

Chapter 4 explores research question (RQ1.a) by providing a conceptualization of the publication decisions in university-industry projects, and how the type of knowledge outcome, legal setting and partnership characteristics may influence the publication decision. Chapter 5 examines research question (RQ1.b) and the suggested relationship between project objective and dissemination (M. Perkmann & Walsh, 2009) and explores whether the degree of industry participation and contribution to projects relates to dissemination in university-industry projects.

- RQ2: To what extent do academics[5] pursue different objectives and produce qualitatively different academic outputs within university-industry projects compared to their purely academic research?

This question (RQ2) goes to the heart of the academic production of knowledge in the context of university-industry projects. Do academics use university-Industry projects as arenas to perform and promote their research agendas or are they pulled or pushed towards new directions? Empirically, we first need to understand whether research is any different when performing it with firms. With knowledge of whether and to what degree research outcomes differ in collaboration with firms, we can we start to theorize about why and which mechanisms may be at stake.

Chapter 6 provides an empirical analysis of the degree to which research outcomes from university-industry projects are different from academics' other research outcomes.

- RQ3: How does collaboration with industry influence the impact of academic research?

There are conflicting ideas of how firms may affect the impact of academic research. Politically, in Denmark, interaction with firms is argued to be beneficial to the advancement of science (Styrelsen for Forskning og Innovation, 2015). On the other hand, others have argued that there are potential risks such as an overly short-term focus, where application and commercial interests may outweigh methodological rigor and documentation (Behrens & Gray, 2001; Florida, 1999). Finally, there may be credence to the notion that collaborative research between academics and firms offer both benefits and costs to

[5] In this dissertation, *Academics* are researchers employed in public research organizations.

scientific impact. Therefore, this empirical question is important to understand whether there is some inherent value or cost to academic research production with firms.

Chapter 7 provides an analysis of the extent to which published outcomes from university-industry collaborations compare to other types of collaborations in terms of citation impact and whether academics produce research that receives more attention when collaborating with industry versus other academics.

Chapter 2: Background

In this chapter, I provide insights from the scholarly literature concerning academic research in the context of university-industry collaboration. The chapter draws on empirical studies of university-industry interaction, technology transfer and academic engagement, as well as theoretical contributions in the field of *economics of science* (Dasgupta & David, 1994; P. E. Stephan, 1996). Specifically, I introduce and discuss literature that addresses 1) the direction and focus of academic research in the context of university-industry collaboration, 2) the complementarity between university-industry collaboration and academic research production and the scientific impact of research produced within university-industry projects and 3) the dissemination of academic research in the context of university-industry collaboration.

First, I introduce relevant concepts related to university-industry collaboration and the economics of science. I provide arguments for why it is relevant to explore how the production and public dissemination of scientific knowledge is affected by the participation of industry in academic research within university-industry projects. Second, I present current understandings of university-industry collaboration and academic research production. Third, I discuss the empirical evidence in relation to when and to what extent university-industry collaborations lead to the dissemination of academic research findings. Fourth, I discuss what the literature finds in relation to the scientific impact of published research produced within the context of university-industry collaboration. The chapter concludes with an overview of the gaps in the literature and how they are addressed in this dissertation.

2.1 Knowledge production and dissemination in the context of university-industry projects

In this section, I provide a short overview of the basic assumptions and theoretical understandings of the "rewards structures" in science and industry and how these structures shape firms' and *Scientific knowledge*' decisions regarding knowledge production and disclosure in the context of research and development activities[6]. This provides a toolbox for the opening of questions of how knowledge production and dissemination occurs in the context of university-industry projects.

[6] For an expanded discussion, I refer to chapter 4 of this dissertation

The study of university-industry collaboration is as much about the interaction of two different sets of objectives and norms, as it is about the exchange and co-production of knowledge. As Dasgupta and David (1994) state:

> [...] what fundamentally distinguishes the two communities of researchers is not their methods of inquiry, nor the nature of the knowledge obtained, nor the sources of their financial support. To be sure, differentiations between can be drawn along those lines [...] It is the nature of the goals accepted as legitimate within the two communities of researchers, the norms of behavior especially in regard to the disclosure of knowledge, and the features of the reward systems that constitute the fundamental structural differences between the pursuit of knowledge undertaken in the realm of Technology and the conduct of essentially the same inquiries under the auspices of the Republic of Science (Dasgupta & David, 1994, p. 495).

Within the sociology of science Merton argued that the science system incentivizes academics to publish research findings in academic literature and to do so rapidly through the mechanism of "priority of discovery" (R. K. Merton, 1969). Priority of discovery is also a central assumption in the theoretical approach within economics of science. An economic interpretation of Merton's sociological analyses of science is the fundamental currency in science is the "*reputation gained by individuals for 'contributions' acknowledged within his or her collegiate reference groups" (Dasgupta & David, 1994)*. In order to gain reputation in the scientific system individuals must be the first to stake their claim of discovery by openly sharing their knowledge claims. Importantly, the assumption is that only the first to stake a claim is credited. There is little to no reputational gain for coming in second. Therefore, not only is there an incentive to openly share and publish research findings and developments, but to do it in a timely fashion. The main way of staking a claim is by preparing a manuscript, which is submitted to a journal where peers review the content. The mechanism of priority of discovery is claimed to affect central decisions in academic work, from choosing which scientific "contests" to engage in to whom to collaborate with (Paula E. Stephan, 2010). While reputation is the fundamental currency within science, academics are not excluded from financial gains from their research. Moreover, it is not uncommon for academics to engage in secretive behaviour (Mitroff, 1974). Purposefully withholding knowledge, equipment and methodologies for the sake of personal enrichment, however, may come with substantial costs to academic reputation and esteem in the scientific community. In general, university academics are expected to publish scientific discoveries and developments. This is reflected in the way both governmental and private funding is allocated to a large degree based on the applicants' number of publications and their perceived impact in the scientific community. Specific publication counts and publication in perceived high quality journals are often needed for promotions for permanent positions in universities (Franzoni, Scellato, & Stephan, 2011). Thus, at the margins, choosing to withhold publishable knowledge may have significant effects on academic careers.

Firms on the other hand are driven by profit maximization and choices to invest resources in research and development projects are driven by the expected return on investment (Nelson, 2004; Rosenberg, 1990). Maximizing returns on investments in knowledge production is often dependent on the ability to keep potential competitors from entering the market through replicating an invention or accessing and utilizing commercially relevant knowledge. By protecting the knowledge, firms can maintain a competitive advantage allowing for example to extract monopoly rents for an extended period of time (Rosenberg, 1990). Therefore, firms will often prefer to withhold commercially valuable knowledge or attempt to secure property rights through patenting.

When firms and academics collaborate, the question is whether the reward systems can co-exist; can firms realize a sufficiently high rate of return on investments while academics can produce and publish reputation-building knowledge? It is the perceived tensions between the reward systems that has been the background for concerns of how increased interaction with firms may affect academic knowledge production and dissemination (Dasgupta & David, 1994; Florida, 1999; Geuna, 2001; Slaughter & Leslie, 2001). The increased participation between industry and academia may have a negative effect on the pursuit and publishing of relevant discoveries and advances because firms may pressure or compensate academics so they forego or delay publishing (Geuna, 2001).

While maximizing returns to investments often require patenting or secrecy, firms do engage in research even if there are many benefits that they may not be able to protect. As Rosenberg states:

> Even if a firm's basic research generated many benefits that it could not appropriate, the mere existence of such non-appropriabilities is never an adequate explanation for the reluctance to perform basic research. All that is necessary is that market forces allow the firm to capture enough of these benefits to yield a high rate of return on its own investment in basic research (Rosenberg, 1990, p. 167).

Firms may be able to realize sufficient return on investments by alternative means of protection. While patenting and secrecy often will provide the highest return on investment, inventions and relevant knowledge still may provide sufficient returns through first-mover advantages. A short delay in publication of knowledge or strategic omissions of central pieces of knowledge may be sufficient for firms to maintain a competitive advantage. Moreover, firms may specifically engage with academics in projects to build absorptive capacity and connectedness (Cockburn & Henderson, 1998) The return on investment in these cases come in the form of building human capital and goodwill with actors in the scientific system.

Similarly, academics can benefit from interacting with industry without immediately publishing. Stephan argues that patenting has become a core element of the academic reward system (P. E. Stephan, 2008). Moreover, patenting first and publishing subsequently after is a common option when scientific findings are potentially commercially relevant (Mohan-Ram, 2001). In fact, in many systems academics are either encouraged or legally obliged to report inventions to technology transfer offices, so that appropriate protection can be pursued(Mowery & Sampat, 2004). Moreover, as mentioned above, academics engage in secrecy to reap alternative economic benefits from research projects.

It is not only the reward system that is of importance when discussing knowledge production in university-industry projects. Academics and firms have different quality criteria when it comes to knowledge production (Dominique Foray & Francesco Lissoni, 2010). If projects are guided by the quality criteria of firms, the knowledge that is produced may not be academically relevant or produced in a way that is accepted as scientific by academic peers. If projects are guided by scientific quality criteria, however, there may be a tension between speed and usefulness and rigor and generalizability. Foray and Lissoni (2010) describe in the following quote the potential tensions between quality criteria within industrial and academic research.

> On both the academic and industry sides, "optimal quality" is sought. However, views on what is optimal are not the same. From the point of view of academic research, optimal quality will entail the novelty gap or inventive step, elegance of the solution, or importance and generality of the new knowledge (able to generate cumulative effects across different fields). From the industry point of view, optimal quality entails cost effectiveness, reliability of the new system, time to market, and economic availability of the various inputs of the new production function. This is a major tension: academic researchers are looking for hyper-innovative solutions which can fuel interesting and challenging discussions among colleagues while industry engineers are focusing on reliability and cost-effectiveness. (D. Foray & F. Lissoni, 2010, pp. 285-286).

In the sections below, I discuss how the production of publishable knowledge (that which may led to reputational benefits in the science system) is pursued in projects where firms and academics engage in projects together. First, I introduce what university-industry projects are, how they are organized, and provide an overview of how they are typically categorized in the study of university-industry collaboration.

2.2 University-industry projects and university-industry collaboration

Science and industry interact directly and indirectly in many ways. Knowledge and resources are transferred, exchanged and created between the two. The connections between university and industry are often referred to as links, relationships, collaborations and interactions. Connections span from mobility of human resources between the two sectors and the use of academic literature in industrial R&D, to industrially sponsored research, collaborative research and development projects, and academic consultancy.

In their study of sectoral patterns in the 'knowledge interactions' between universities and industry in Austria, Schartinger and colleagues define knowledge interactions as "(...) all types of direct and indirect, personal and non-personal interactions between organizations and/or individuals from the firm side and the university side, directed at the exchange of knowledge within innovation processes" (Schartinger, Rammer, Fischer, & Fröhlich, 2002). M. Perkmann and Walsh (2007) propose a typology of university-industry links based on the extent of relational involvement in knowledge interactions. They arrive at three categories: Relationships, Mobility and Transfer. 'Relationships' include a high extent of relational involvement and is comprised of research partnerships and research services. 'Mobility' refers to the transfer of knowledge through human resource mobility between sectors and 'Transfer' refers to the transfer of knowledge through licensing.

University-industry projects are such interactions with a high relational involvement. University-industry projects take on different forms and are organized in a variety of ways. Some projects are highly collaborative with both academics and firms performing key tasks, while others are mainly or exclusively performed by the academic project participants (A. McCabe, R. Parker, & S. Cox, 2016). The funding structure of projects can also vary and often relate to the division of tasks (M. Perkmann & Walsh, 2009). Firms may fund all project tasks, third parties may fund partially or entirely the activities of the project, and funding between parties may consists of cash transfers and in-kind contributions. The objectives of the projects also vary, with some focused on primarily commercial objectives and others on traditional fundamental research objectives. The expected outputs range from practical and technical solutions for use in firms to technological and scientific advances.

Most importantly, university-industry projects are university-industry links in which firms are most actively involved with academics (M. Perkmann & Walsh, 2007), as they fund, participate and can influence the objective and content of academic work.

Typical categories of university-industry projects are collaborative research and development projects, sponsored or contracted research projects and consultancy or research services. Consultancy refers to the relationship between the researcher as a consultant who performs a project and delivers advice or consultancy to the firm who has a problem or question, which it needs advice or knowledge about and pays for the service (D'Este & Patel, 2007; OECD, 2013; M. Perkmann & Walsh, 2007). In some definitions, it is explicitly stated that consultancy does not involve original research while others include research as a possible activity (D'Este & Patel, 2007). Sponsored or contracted research refers to the relationship between the firm and researcher, where the firm sponsors/contracts a research project within a field. The researcher is a recipient of the sponsorship and performs a project within the scope of the agreement (OECD, 2013; M. Perkmann & Walsh, 2007).The word research here refers to the content being research rather than a service, the only element that formally sets it apart from consulting. The difference between sponsored and contracted research refers to the autonomy of the researcher. In sponsored research, the researcher receives funding for an area of research of interest to the firm but has the freedom to choose how and can change direction easily. In contracted research, the firm designs the objective and even the methods to which the researcher shall perform the project. Collaborative research and development projects are defined by the fact that both parties jointly commit resources and research efforts to a common goal. The goal can range from fundamental research to technology development and demonstration (OECD, 2013; M. Perkmann & Walsh, 2007).

University-industry projects may be categorized in terms of their objective and the extent to which objectives align with academic knowledge production compared to commercial aims. The most frequently used distinction, although seldom defined in detail, is “basic” and “applied” projects. Often consultancy and contract research are referred to as applied and joint research as fundamental or basic (e.g in D'Este and Perkmann (2011)). However, collaborative projects are also defined in terms of their appliedness. In some cases, the applied-basic distinction refers to the scientific goals, others times to the degree to which objectives are commercial or explorative. Essentially, it is assumed that if projects are applied from the perspective of the firm they are also to the academic. Yet, projects can explicitly target the development of a new technology (applied) and attempt to understand underlying phenomena simultaneously (Stokes, 1997). The basic-applied distinction implies a linear view of science and innovation, and can often be more confusing than useful. However, it can be relevant and necessary to distinguish between projects that are mainly motivated by commercial and practical objectives and those that are mainly focused on producing scientific knowledge that are motivated by expanding and improving the understanding of natural and social phenomena. Bozeman, Fay & Slade (2013) distinguish between collaborative projects that are *knowledge focused* "aimed chiefly at expanding the base of knowledge" (p. 4) and *property focused* "[collaborations] focused on production of economic value and wealth" (p. 4). However, Bozeman et al. (2013) acknowledge that projects often aim at expanding the base of knowledge *and* creating economic value simultaneously. Perkmann and Walsh inductively derive a four-fold typology of university-industry projects. Projects are placed on a "degree of finalization" continuum where finalization refers to "the degree to which scientific research pursues a specific purpose as opposed to gaining new knowledge for the sake of itself" (M. Perkmann & Walsh, 2007, p. 268). From most to least finalized, the four types include:

- Problem solving projects, defined as projects where "[academics provide …] advice regarding technical problems arising within a firm's R&D, manufacturing or other operations".
- Technology development projects, aimed at "[d]eveloping design specifications or prototypes for new or improved products or processes".
- Ideas testing projects, that aim at "[e] xploring a high-risk concept on behalf of a firm – outside the firm's mainstream activities".
- Knowledge generation projects where project participants "[c] arry out research on topics of broad interest to a firm"(M. Perkmann & Walsh, 2009, p. 1046).

Knowledge generation projects roughly correspond to Bozeman's definition of knowledge-focused projects while the three remaining types reflect different degrees of property-focused projects.

Drawing on the above, in this thesis I define university-industry projects as formalized interactions delimited by a common objective, deliverables, sets of task, timeframe and budgets between academics and firms where both parties contribute to the reaching the common objective by pooling resources, financial or human.

The concept university-industry collaboration has often been used to describe this type of interaction (Ankrah & Al-Tabbaa, 2015; A. McCabe et al., 2016). In comparison with university-industry projects, university-industry collaboration is both narrower and broader. Bozeman et al. defines collaboration as "social processes whereby human beings pool their human capital for the objective of producing Knowledge." (Bozeman et al., 2013). Thus, projects that do not pool human resources are not collaborative *per se*. This definition can exclude industrially sponsored research projects and consultancy projects or at least cause confusion to whether or not they are university-industry collaborations. The definition also includes informal collaborations that do not have a formal organization of work. Therefore, I use the concept university-industry projects in order to include all projects where firms and academics pursue a common goal in a formally organized and contractualized setting. The distinction between university-industry collaboration and university-industry projects is very fine-grained and can for the most part be used interchangeably. Therefore when referring to collaboration between academics and firms more broadly I use university-industry collaboration to stay in line with the literature. I use university-industry projects when it is important, mainly for the purpose of empirical analysis.

2.3 The pursuit and production of academically relevant research within university-industry projects

When are university-industry projects conducive to the production of reputation-building knowledge claims? Given the differing orientations between academic and industrial research, questions have been raised about how university-industry projects influence academic research. The potentially conflicting reward systems and quality criteria within science and industry respectively, raises questions concerning the pursuit of academic knowledge within university-industry projects. In this section, I discuss what has been offered by the empirical literature in answering how academic knowledge production is pursued within university-industry projects.

Considerable empirical work has been performed on the academic consequences of engaging in activities with industry (Larsen, 2011; Markus Perkmann et al., 2021; M. Perkmann, Tartari, McKelvey, Autio, Brostrom, et al., 2013). These empirical studies do not directly investigate how and to what degree academic knowledge is produced within university-industry projects. However, they provide empirical evidence of how the intensity and impact of academic knowledge production correlates with engagement with industry. This in turn used as indications of the extent to which university-industry projects are conducive to academic knowledge production.

Studies find that, on average, receiving research funding from industry is positively related to academics' productivity in terms of number of publications (Blumenthal, Campbell, Causino, & Louis, 1996; Gulbrandsen & Smeby, 2005). However, compared to receiving public funding the relationship is found to be either small (Gulbrandsen & Smeby, 2005) or negative (Hottenrott & Lawson, 2017). Thus, academics who receive funding from industry tend to publish the same amount overall as colleagues who receive funding from other sources, and more than peers who do not receive any external funding. The type of projects that are funded by industry are not always explicit in these studies, as they rely on self-reporting. Therefore, it is not clear what type of projects these academics engage in. For example, in the study by Gulbrandsen and Smeby (2005), the survey question referred specifically to "research funding from industry" (Gulbrandsen & Smeby, 2005). Hence, respondents may not include funding for consultancy and contract research – moreover, it is not obvious whether research projects with the participation of firms or in-kind funded projects are included in these measurements.

Studies find that the positive relationship between industrial funding and academic productivity is decreasing in terms of intensity of industry funding relative to public funding (Manjarres-Henriquez, Gutierrez-Gracia, Carrion-Garcia, & Vega-Jurado, 2009). Several studies indicate that academic productivity tends to be mainly positively related to engagement in projects that are focused on traditional academic research objectives, while engagement in contract research and consultancy has a negative relationship with subsequent academic productivity (Fudickar, Hottenrott, & Lawson, 2018; Manjarres-Henriquez et al., 2009; Rentocchini, D'Este, Manjarrés-Henríquez, & Grimaldi, 2014).

A common interpretation provided in the literature is that engagement in industry-funded projects may complement academic research, yet only up to a certain point where industry funding can crowd out academic productivity in favor of more commercial and application-oriented activities and outputs (Manjarres-Henriquez et al., 2009). In their review of this body of literature (Markus Perkmann et al., 2021), conclude that "*academic engagement is complementary to, and in line with, furthering academic research activities*" (p. 7). In their survey-based study of academic motivations for engagement D'este & Perkmann, (2011) provide an argument in line with Perkmann et al. (2021). They argue that academic researchers are motivated to engage with firms to promote their research. However, researchers derive academic benefits from "commercial projects" (contract research and consultancy) indirectly, through access to funding and learning from industry and that these types of projects "rarely" lead directly to academically relevant research outcomes. While participation in Joint R&D, which they assume is more focused on knowledge generation is more likely to lead directly to relevant academic knowledge (D'Este & Perkmann, 2011). In a qualitative study of engineering faculty participation in university-industry projects, Perkmann and Walsh (2009) found that projects close to the commercial frontier were unlikely to lead to academically valuable or relevant findings, while projects that focused on "knowledge generation" were conducive to pursuing academic knowledge production. Moreover, projects at the intermediate level tended to lead to both academically valuable outcomes, as well as commercially relevant knowledge. Thus, the more objectives are aligned with firm's commercial objectives the less academically relevant the findings were. However, they argue that there are learning benefits from engaging with industry that led to follow-on projects and new ideas and insights. These benefits occur more often in projects that have commercial objectives, as they are more interactive, and learning requires interaction (M. Perkmann & Walsh, 2009).

The literature thus tends to distinguish between projects that are directly and indirectly complimentary with traditional academic research objectives. Thus, projects that are "knowledge-focused" tend to lead directly to scientific research outcomes and "property focused" tend to lead to academic benefits indirectly – through access to research funding and learning from industry. Overall, the consensus in the literature on academics engagement, is that engaging with industry is "*complementary to, and in line with, furthering academic research activities*" (Markus Perkmann et al., 2021, p. 7).

2.4 (When) are knowledge outcomes from university industry projects published?

While projects may lead to potentially academically relevant knowledge outcomes, which academics are incentivized to publish, the dissemination choice is affected by the fact that publication of knowledge can potentially incur a cost to firms if the publication of such knowledge affects the possibility to protect and appropriate value from the knowledge outcomes. The argument provided in the literature is that specific types of projects lead to academically relevant knowledge, while other types led to academic benefits indirectly – hence academics on average benefit academically from engaging with industry. Somewhat fortunately, authors argue that projects that could lead to secrecy issues due to the commercial relevance of knowledge often do not lead to "academically relevant" findings but instead provide learning benefits. And, projects that lead to academically relevant findings often do not lead to commercially valuable knowledge (D'Este & Perkmann, 2011; M. Perkmann & Walsh, 2009).

However, knowledge production is an inherently uncertain process. Therefore, projects no matter the initial objective may lead to publishable findings. The question is when such knowledge outcomes are codified and shared with academic peers, and when publishing of relevant knowledge is deselected or hindered. In a qualitative study of university-industry interactions. Crespo and Dridi (2007) found that questions of intellectual property rights and conflicts of interest were a source of stress and tension for researchers in university-industry projects. However, issues were always resolved. Based on 43 interviews at an engineering faculty at a UK university, Perkmann and Walsh (2009) examine publication behaviour in 55 university-industry projects. Projects with a low degree of finalization were conducive to academic publishing because the content was similar to traditional research projects and thus relevant to the scientific community. In addition, the outputs of the projects were not immediately commercially valuable. Therefore publishing did not affect the sponsoring firm's commercial opportunities. Projects with an intermediate to high degree of finalization tended to suffer from *relevance issues*. Findings were not academically relevant or the methods were not sufficiently rigorous for scientific publication. They found that projects with an intermediate to high degree of finalization were more likely to exhibit secrecy issues that limited academic publication. Academics postponed publishing for appropriation reasons or firms demanded secrecy to protect commercial opportunities.

The important take-away from Perkmann and Walsh (2009) is the notion that secrecy issues occur when projects lead to both academically and commercially relevant knowledge. They argue that this will most often happen in projects that aim at "[e]xploring a high-risk concept on behalf of a firm – outside the firm's mainstream activities" or "developing design specifications or prototypes for new or improved products or processes"(M. Perkmann & Walsh, 2009, p. 1046). Therefore, due to relevance and secrecy issues, Perkmann and Walsh argue that publication in university-industry projects is negatively related to the degree of project finalization. Callaert et al (2015) find that academics who report being the instigators of university-industry projects also report that projects lead to more publication outputs. This corresponds to Perkmann and Walsh's findings that the less finalized, the more likely projects are initiated by academics (Callaert, Landoni, Van Looy, & Verganti, 2015; M. Perkmann & Walsh, 2009). Moreover, projects initiated by academics may more often be designed with scientific quality criteria in mind. Finally, projects initiated by firms were found in Perkmann and Walsh (2009) often to be projects where firms were only involved in a minor role. Therefore, the potential for them to steer the project towards commercial objectives may be significantly lower than in e.g. contracted research projects. In a study of research projects funded by EPSRC, Banal-Estanol et al (2013) find that collaborating with firms that have an above-average history of publishing in academic literature is also positively related to publishing in this type of university-industry project (Banal-Estanol, Macho-Stadler, & Perez-Castrillo, 2013). This may reflect that firms who engage in scientific projects for the purpose of building absorptive capacity and building goodwill and connectedness with academic environments select into projects with a high academic focus. While firms that participate in projects to more directly pursue commercial ideas and opportunities select into other types of projects where they can control the process to a higher degree.

What has not been empirically investigated so far is how the degree of funding and participation of projects relates to whether projects lead to publication. It is likely that firms will invest more heavily in projects where they expect commercial outcomes. Therefore, the pressure not to share valuable knowledge may be higher. Similarly, projects where firms only participate in a minor role are likely projects where firms participate in order to build absorptive capacity, gain access to the scientific frontier and build up goodwill with the scientific community.

There is a need therefore to investigate at the project level, examining the degree to which the argued relationship between finalization and publication is visible in empirical data. How often do projects that are highly or moderately finalized lead to publications compared to those that are at a low level of finalization? Moreover, do other factors relate to the extent to which projects lead to publications? Does the intensity of firm contribution and participation in projects relate to the likelihood that projects lead to published outcomes? I examine these questions in Chapter 5.

2.5 What type of research is pursued in university-industry projects?

A central question is what type of knowledge is pursued and published within university-industry projects. Does knowledge generated by academics in university-industry projects reflect the research portfolio of the academics involved? Are university-industry projects arenas where academics can try out different research questions? Are academics pushed or pulled in certain directions by firms? There have been critical and concerned voices noting that interaction with industry may cause academic research to move towards more short-term, application-oriented research at the expense of fundamental scientific inquiry (Florida, 1999; Geuna, 2001). However, the extent to which academics pursue and publish research of a different nature with industry than they do otherwise is underexplored.

University-industry projects are generally described as more application oriented than academic research projects. Publications derived from industry-funded contract research or collaborative research might be more applied as project objectives result from a compromise between industrial and academic objectives (Webster, 1994). Additionally, the more property focused the more application-oriented research outcomes are expected to be. Projects that focus on materials and technologies may lead to academic results relevant to fields of science that focus on these technologies and materials.

Theoretically and empirically, we know that projects that are focused on practical problems can lead to fundamental breakthroughs, just as fundamental research can lead to immediately commercial solutions (Stokes, 1997). Hence, the academic outputs from projects need not be “applied” because the project has practical and use-centered objectives.

Empirically, there is little evidence to suggest that academics publish research that is more “applied” within university-industry projects than in their academic collaborations. However, there are not many studies on this subject.

If academically relevant research outcomes mainly are derived in projects that resemble academic research projects, the direct outcomes will likely reflect the academics research portfolio in general. If projects of more commercial nature do in fact lead directly to academic findings, they may on the other hand, differ from the academics’ overall portfolio. As firms may provide insights, technological problems and materials that may lead to novel research outcomes.

We know however, that academics who describe their research as applied are more likely to engage with industry. This suggests that perhaps academics select into projects that they expect to be conducive to their research agenda. In fact, surveys indicate that academics are mainly motivated to engage with firms to further their own research (D'Este & Perkmann, 2011).

In Chapter 6, I investigate to what extent academics pursue and publish research of a different nature with industry to understand more closely how industry participation in the research process may relate to the direction of science at the level of the individual academic.

2.6 The scientific impact of academic research produced within academia

A central discussion is to what extent the research produced between firms and academics has an impact within the scientific community. To what extent does research produced in collaboration between firms and academics lead to research that has an impact in the scientific community compared to research produced within the academic system. On one hand, political decision-makers argue that increased interaction between academics and firms is a necessary component to improve the impact of science (Styrelsen for Forskning og Innovation, 2015). On the other hand, there is limited theory to back up any claim that collaboration between firms and academics would produce more or less impactful research than other forms of collaboration.

Inspired by the mainly politically motivated discussion, studies have attempted to assess the impact of knowledge outcomes of university-industry collaboration. A few studies have focused directly on the impact of publications co-authored by firms and academics, assuming that they are a result of collaboration (Lebeau, Laframboise, Lariviere, & Gingras, 2008). Others have examined the citation impact of academic publications published in the period after engagement with industry (Banal-Estanol, Jofre-Bonet, & Lawson, 2015; Manjarrés-Henríquez, Gutiérrez-Gracia, Carrión-García, & Vega-Jurado, 2009).

Hottenrott and Lawson (2017) find that receiving funding for research is positively related to the expected number of publications and citations of an academic. However, they also find that both publication and citation counts are higher for academics who only receive funding from public sources, than those who receive from both. In this study, they equate raw citations over five years and journal impact factor as indicators of research quality. This type of study, however, does not provide information to the impact or citation counts of publications directly related to projects performed with industry. (Lebeau, Laframboise, Lariviere, et al., 2008) examine bibliometric data for Canada in the period 1980-2005. They find that publications co-authored by academics and firms tended to be published in lower impact journals than academic only, or firm only publications, however, they received on average a higher field normalized citation scores. This could indicate that the citation impact in the scientific community is on par or even higher for research produced in collaboration between firms and academics. However, the study does not take into account potential confounding factors, such as the number of co-authors, number of organizations, whether authors are from the same or different countries or the past citation impact of collaborators. These are all factors known to correlate with impact (Katz & Hicks, 1997).

Some questions are therefore still unanswered. How do university-industry co-authored publications compare with co-authored papers by academics based in the same or different countries? Does the impact of university-industry co-authored publications relate to the characteristics of the academic involved? When taking into account the basic characteristics of publications is there a positive relationship between expected impact and university-industry collaboration compared to other collaborations? Chapter 7 of this dissertation provides an empirical analysis of Danish publication data, which attempts to provide answers to these questions.

2.7 Summary and moving forward

In this chapter, I presented the empirical and theoretical literature relevant to the question of how production and dissemination of scientific knowledge is affected within university-industry projects.

The economics of science provides a basic theoretical understanding of the reward systems facing academics and firms. Applying this theory to the specific question of knowledge production and dissemination in university-industry projects, we expect that knowledge production may be affected and publication may be hindered by the conflicting rewards systems and quality criteria of science and industry. The scholarly literature on university-industry interaction argues that there rarely is conflict in terms of publication or secrecy, since projects rarely lead to knowledge outcomes that are commercially and academically relevant simultaneously. Moreover, empirical research suggests that on average engaged academics produce similar amounts of publications compared to their peers. However, empirical research also indicates that *when* projects lead to both commercially and academically relevant knowledge, secrecy issues do occur. While empirical evidence suggests that the objective of a project affects the publication decision, we lack empirical knowledge of the extent to which the objective of a project relates to the publication of project related knowledge. Additionally, we lack an understanding of whether and how this observed relationship exists outside the context studied.

Other aspects have been found to relate to whether university-industry projects lead to publication. Projects initiated by academics and projects with participation of firms with above average publication track-record are related to a higher level of publications. However, the degree to which firms participate and contribute to projects, which theoretically could indicate the expected return on investment, may relate to the degree to which projects lead to publications. Yet this has not been empirically investigated. Moreover, the current theoretical understanding of the publication decision in university-industry projects is based largely on empirical observations of how project characteristics and publication outcomes correlate. In Chapter 4 of this dissertation, I conceptualize the publication decision in university-industry projects integrating economics of science with empirically grounded theory.

An often-stated concern has been that interaction with industry may affect the direction of academic research. However, the question of whether research is skewed towards applied research at the expense of fundamental research has not been investigated in depth. Studies have shown that academics engaged in university-industry projects identify their research as applied more often than their peers. A single study found that academics do not publish more in applied journals after engaging in inventive activities (Van Looy et al., 2006). Thus, there are empirical indications that academics select into projects and activities that are aligned with their overall research direction or that they are not pulled or pushed in specific directions. Yet, there, is an empirical gap related to whether academics pursue and publish research that is different when they engage with firms. While the skewing may still occur at the systemic level, knowledge at the micro-level can provide needed knowledge to the overall problem.

It has been argued, politically, that interaction leads to impactful research. Yet, only limited research has attempted to examine this question, primarily with simple correlational studies that are unable to account for mediating factors. Empirically, studies have found citation impact to correlate positively with university-industry co-authorship while ambiguous results regarding journal impact factor. Similarly, an ambiguous picture emerges in terms of the citation impact of published research of academics involved in university-industry projects. Therefore, there, is an empirical gap related and a need to address the open questions that are left unanswered.

In the next chapter, I provide an overview of how I investigate these problems and provide a detailed discussion of the methodology of the dissertation.

Chapter 3: Approach, methods and data

The aim of this chapter is to provide an overview of the empirical and theoretical chapters of this dissertation. I describe how each chapter approaches the research questions posed, and describe the data and methods used.

This dissertation is empirically situated in a Danish context, and utilizes data sources detailing university-industry projects as well as Danish publications. Moreover, theory from economics of science and empirical literature from multiple fields of research is combined to provide a conceptual framework of how the publication decision is determined in a university-industry project.

Chapters 4 through 7 each provide analyses that inform the overarching question of how the production and public dissemination of scientific knowledge is affected by the participation of industry in academic research within university-industry projects**.** Production and public dissemination refer specifically to the three topics: Direction, dissemination, and impact of knowledge in the context of university-industry projects.

Chapters 4 and 5, respectively, examine the question of dissemination conceptually and empirically. Chapter 6 empirically examines the question of direction of research. Chapter 7 empirically examines the question of impact of research. Together they provide insights into how academic knowledge production and dissemination is affected within university-industry projects when industry is actively involved in academic work. The empirical work is based on Danish publication data and project-level data from the faculty of science and technology, Aarhus University. Denmark. Therefore, the empirical insights and results are primarily relevant to a Danish context. However, there are aspects that can be generalized more broadly.

The current chapter begins by summarizing the knowledge gaps identified in Chapter 2. I present and describe how chapters four through seven contribute and approach the knowledge gaps. In the second section, I provide a description of the Danish research and innovation system with special attention to university-industry collaboration in the Danish research and innovation system. Additionally, I provide background information on the faculty of Science and Technology, Aarhus University. In particular, I provide a brief description of the structures for academic collaboration with firms at the Faculty. In the fourth section, I provide an overview of the central data sources and the methodological steps taken to create the datasets used in this dissertation.

3.1 Approach

In Chapter 2, I introduced three areas of interest with regard to the overarching problem statement: how the production and dissemination of scientific knowledge is affected by the participation of industry in academic research within university-industry projects. These are: the direction of academic knowledge production in university-industry projects, the dissemination of knowledge in university-industry projects and the scientific impact of knowledge in university-industry projects. Here, I provide a summary of how chapters four through seven approach the three topics.

3.1.1 Dissemination

The economics of sciences provides a basic theoretical understanding of the incentive structures academics and firms face when deciding on how and whether to disseminate academically relevant knowledge produced within the confines of a university-industry project (Dasgupta & David, 1994; R. K. Merton, 1969; Nelson, 2004; Rosenberg, 1990; P. E. Stephan, 2004). The structures suggest that there is an inherent conflict between academic publishing and commercial appropriation (Dasgupta & David, 1994). Until know empirical literature has argued that if knowledge outcomes are both commercially and academically relevant, publishing is less likely (D'Este & Perkmann, 2011; M. Perkmann & Walsh, 2009). Based on empirical studies, scholars tend to argue that there often is little conflict between academic publishing and appropriation in university-industry projects and in fact engagement with industry is conducive to academic research (Gulbrandsen & Smeby, 2005; Markus Perkmann et al., 2021). While the correlation between engagement with industry and research production may be positive, understanding when publication may be foregone or delayed in university-industry projects is currently under researched. I argue that there is a need for a conceptualization of when knowledge outcomes are published in scholarly literature. The first research question therefore addresses **how is the decision regarding publication of knowledge outcomes in university-industry projects determined? (RQ1.a)**

Chapter 4 asks under which circumstances university-industry projects lead to the publication of knowledge outcomes. The conceptual chapter addresses the question within the framework of the economics of science. It utilizes empirical and theoretical literature from various fields that have investigated university-industry interaction, including, economics of innovation, technology transfer and research policy. This chapter provides a conceptual analysis of when projects partners have conflicting preferences concerning publishing, and importantly, how a publication decision is reached in cases of apparent conflicts.

Empirical evidence suggests that the objective of a project affects the degree to which projects lead to publications (M. Perkmann & Walsh, 2009). Yet, we lack empirical quantitative knowledge of the extent to which the objective of a project relates to the publication of project related knowledge. Moreover, other project characteristics than the objective have been empirically found to correlate with publication in university-industry projects, while other projects characteristics theoretically could have an impact on the publication decision. In this dissertation I ask: **To what degree do university-industry projects lead to knowledge disseminated in academic literature, and do specific project characteristics or types of projects affect or relate to the choice of dissemination? (RQ1.b)**

Chapter 5 addresses this question through the analysis of a sample of 117 university-industry projects with the participation of academics affiliated to the faculty of Science and Technology, Aarhus University. Utilizing a combination of document analysis, linking of projects to publication outcomes and regression methods, the chapter examines to what degree university-industry projects lead to knowledge disseminated in academic literature. Specifically, to what degree the objective of the project, as defined by Perkmann and Walsh (2009), and the degree of firm participation relates to the probability and number of project-related publications. The study aids in understanding whether previous empirical findings are observed in a Danish context and provides a quantitative estimate of the degree to which the objective of a project relates to the publication outcomes. The study takes into account a number of factors previously shown to relate to publication outcomes in academic research in general and university-industry projects specifically. This includes the size and duration of the project. The study not only examines whether projects lead to publications, but whether publication of knowledge is delayed dependent on the objective and firm participation in projects.

3.1.2 Direction

An often-stated concern has been that interaction with industry may affect the direction of academic research (Behrens & Gray, 2001; Florida, 1999). Yet, there is an empirical gap related to whether individual academics pursue and publish research that is different when they engage with firms. This dissertation, therefore, asks**: To what extent do academics pursue different objectives and produce qualitatively different academic outputs within university-industry projects compared to their purely academic research? (RQ2)**

Based on a bibliometric analysis of publication profiles of a sample of 115 academics affiliated to Aarhus University, Chapter 6 examines to what extent academics pursue different objectives and produce qualitatively different academic outputs within university-industry projects compared to their purely academic research. The chapter examines the publication portfolio of academics employed at the faculty of Science and Technology, Aarhus University. It compares how similar the textual content and bibliographic references of publications produced in university-industry projects are to the remainder of the academic's publication portfolio. The study contributes to our understanding of whether and to what degree academics pursue and or produce research of a different nature when interacting with firms.

3.1.3 Impact

It has been argued politically that interaction between industry and academia is conducive to producing impactful research. Yet, only limited research has attempted to dive into this question (For important exceptions, see (Godin & Gingras, 2000; Lebeau, Laframboise, Larivière, et al., 2008)). Simple comparisons of publications with and without industry collaboration lack validity as they fail to control for the effects of a number of other differences, such as internationalization and number of co-authors. While studies looking at the effect of collaborative and contract research income on research productivity are not able to provide a direct link between interaction with industry and project related research outputs. Therefore, there is an empirical gap related and a need to address the open questions that are left unanswered. **Is research within university-industry projects of a different impact to research performed in the confines of academia? Does collaboration with industry relate to the impact of academic research? (RQ3)**

Based on bibliometric analysis on publication data, Chapter 7 examines the question: Does collaboration with industry relate to the impact of academic research? The chapter examines the citation impact of publications resulting from university-industry collaboration compared with those produced by academics only. Through multivariate analysis, the study controls for confounding factors such as international collaboration, the number of co-authors and academic discipline. Moreover, by utilizing advanced citation indicators the study improves the validity of knowledge in this area of research. The chapter first examines citation impact for a comprehensive data set covering all Web of Science journal articles with at least one Danish author in the period 1995–2013. Second, we control for potential selection bias by looking at a fixed group of researchers that have both engaged in public-private collaborations and university-only publications. The study examines whether citation impact for individual researchers differs when collaborating with industry compared to work only involving academic researchers.

3.2 Empirical contexts

The empirical analyses in chapters 5, 6 and 7 focus on samples of academics, publications and projects in a Danish context. In this section, I provide a brief description of relevant aspects of the Danish science and innovation system, mainly regarding the emphasis and structures surrounding interaction between academics and firms. Moreover, as two studies specifically deal with academics' publication profiles and university-industry projects at the faculty of Science and Technology, Aarhus University I provide a description of relevant contextual factors concerning university-industry interaction at the faculty. Finally, I answer the question of why I choose this context to study and how it may contribute to understanding the research problem at a more general level.

3.2.1 The Danish research and innovation system and interaction between university-academics and industry

The Danish higher education system consists of eight universities varying in terms of specialization and size. There is a mix of traditional comprehensive universities and mono faculty universities all of which support students and research. Universities are funded through a combination of block grants and competitive funding. The Danish university law of 2003 stipulates that universities have the responsibility to pursue research and provide research-based education and must collaborate with the surrounding society and contribute to the development growth, welfare and development in society. The law also states that the university must exchange knowledge and competencies with the surrounding society (Aagaard, 2012).

Denmark has, as in other developed countries (Geuna, 2001; Mowery & Sampat, 2004), followed a reform trajectory of the science and innovation system emphasizing a higher interrelationship between actors in the national innovation system and continuously altering the science funding system to spur competition and increase the economic and societal value of academic research (Aagaard, 2012). Politically, there has been an emphasis on improving the value of science to society. This comes to the forefront through the political slogan “from research to invoice” coined by a then right-wing government in the mid-2000s (ibid.). The political objective was to improve the economic value of research by incentivizing commercialization and direct collaboration with commercial actors. In recent decades, the block funding to universities has decreased in terms of percentage of funding, while new innovation-oriented research funding instruments have been developed. Total funding allocated through innovation-oriented instruments has increased quickly while the more curiosity driven instruments have stood still relatively speaking (ibid.). Moreover, block funding has in part become dependent on universities' ability to acquire external funding.

From 2007-2017 the number of collaboration agreements between universities and private companies and private foundations rose from 40 % of total collaboration agreements to 53 %. In the same period, the income to universities from these sources more than tripled (*Tal om danske universiteter 2019*, 2020).

3.2.2 The faculty of Science and Technology and the interaction between university academics and industry

The faculty of Science and Technology (S&T), Aarhus University consists of 13 departments covering a variety of scientific fields from agricultural science and food science to computer science, astronomy, and physics. Geographically, the faculty is located in the central region in Denmark. Aarhus University is the second largest university in Denmark. S&T is the largest faculty of the university (measured by full time equivalent staff) that also consists of a Faculty of Arts, Faculty of Business and Social Sciences, and Faculty of Health. In 2017, the faculty of Science and Technology employed 1649 academic staff (FTEs). Some of the departments are new, resulting from a merger in 2007 where the agricultural and engineering school were included in the faculty. These were schools traditionally close with the surrounding industry.

3.2.3 Legal structure for collaboration at Aarhus University

Collaboration with firms is highly formalized and is required to go through the Technology Transfer Office (TTO), where the TTO aids in designing the appropriate contract for the specific purpose.

In the guidelines for collaboration with firms and other external parties, it is stated that a collaboration agreement should always meet three requirements. However, these do not apply to projects where firms fully fund the project.

Information, knowledge and results that university employees produce within a collaborative project must be able to be exploited in the continued research, teaching and research communication. However, a limited period of secrecy can be agreed upon, when a firm has been given the right to review prior to publication or where secrecy is necessary for potential patenting or trademarking. Any secrecy agreements regarding firm secrets must be stipulated as part of the contract for collaboration . The right to academic utilization of results and knowledge, which university employees have produced by themselves or in collaboration must not be impacted by the secrecy agreement.

It must be recognized by the collaborating firms or other parties that academics must be free to publish. However, contracts may stipulate that collaborators are given up to 60 days for review. The collaborating partner can make suggestions to changes and the academic and collaborator must strive to reach an understanding, but the academic will always have the sovereign right to decide what is included in publications. Finally, the collaborating partner can request a 6 month extension on publication in the cases where they wish to file for patent protection.

As a rule, collaborators cannot ex ante be given the right to potential inventions. However, when the collaborating partners co-funding of a projects makes it fair, it is possible ex ante to partially or fully waive the rights to invention in favor of the collaborator. However, this may not affect the academic's possibility to pursue academic utilization of the knowledge produced in the project during or after the project.

3.2.4 Why select Denmark and the ST?

The selection of Denmark and specifically the faculty of Science and Technology as the setting for data collection is primarily due to data access and the ability to apply contextual knowledge to data handling and analysis. A number of the activities for improving data quality when working with the bibliometric data benefited from my knowledge of the Danish science and innovation system. In terms of the selection of the specific faculty, the goal was to access detailed information on a large and varied sample of university-industry projects. By using personal contacts in the university system I was able to gain access to documents that are confidential.

Both Denmark and the faculty in question are integrated in the international science system and therefore bear sufficient similarities that allow for the findings to have relevance to contexts outside of Denmark. The faculty of Science and Technology is organized similarly to other international university faculties and therefore, I expect employees to follow the institutional norms of their respective disciplines. While the legal setting may differ slightly from other nations, industry participation is promoted in the funding system and university system alike, as is the case in most other countries (Geuna, 2001). Therefore, the behaviour of academics and firms are likely similar to that of other academics working in other countries and universities. As academics tend to interact more with firms that are located in close proximity, the specific local environment with regards to industry and which firms are involved with university academics may be very specific to this university. The different strategies of firms in terms of interacting with academics may influence the outcomes that are measured.

Overall, however, results from this specific setting are transferrable to many settings internationally. The most determining factor may be the domestic framework for interacting with industry. It may influence publication decisions to a higher or lower degree than in other countries that have different legal settings and local organizational guidelines.

Many studies in this research area are UK-centric (e.g. (D'Este & Perkmann, 2011; D'Este et al., 2013; M. Perkmann & Walsh, 2009)), with a few studies performed in other European countries (Gulbrandsen & Smeby, 2005; Mora-Valentin, Montoro-Sanchez, & Guerras-Martin, 2004). A study in a Danish context provides the possibility to explore the inner working of science in a different national setting. This type of study can help understand whether findings in a UK or Spanish setting are also relevant in other countries.

The faculty of Science and Technology is an interesting setting because it consists of academics in the traditionally fundamental sciences and those that are what may be referred to as translational or application-oriented sciences. The variety of research fields in the faculty implies a large empirical variation in the type and outcomes of projects.

3.3 Data sources

The empirical chapters of this dissertation rely heavily on two main data sources: bibliometric data accessed through the Web of Science and project data accessed through the contract database, Intuem, at Aarhus University.

3.3.1 Bibliometric data

The Web of Science (WoS) covers publications from about 12,000 journals in the sciences, the social sciences, and the arts and humanities. In addition to the web-based version, I use an enhanced version of the WoS database, developed and maintained by the Centre for Science and Technology Studies (CWTS) at Leiden University. The CWTS in-house version of the WoS database includes a number of improvements over the original WoS database. Most importantly, compared to Thompson Reuters' WoS, the CWTS database uses a more advanced citation-matching algorithm and an extensive system for address unification. The database also supports a hierarchically organized field classification system on top of the WoS "subject categories" constructed by Thompson Reuters. Moreover, the CWTS database offers an author identification algorithm that can aid in identifying authors and their WoS-indexed publications. Finally, the database offers well-documented indicators of collaboration and citation-impact.

The CWTS in-house version of the WoS database contains a number of indicators, which are used in this dissertation. Importantly, impact indicators are field normalized, which makes them more efficient indicators of citation impact than for example journal impact factor, or raw citation counts (L. Waltman & N. van Eck, 2013). I use collaboration indicators, which indicate whether publications are authored by authors from the different institutions, countries, and types of organizations. Moreover, I use indicators of citation impact, including normalized citation score, normalized journal citation score, proportion of publications cited in the top 1, 5 or 10 percent of publications.

According to Merton citations generally indicate that other researchers have found the publication useful in their research and can be seen as a form of peer recognition, an acknowledgement of the contribution of others' work (Robert K. Merton, 1988). However, studies have shown that not all citations have a central relevance to the main issues addressed in the citing author's paper (Bornmann & Daniel, 2008). However, in general, studies have concluded that citations are an imperfect but reasonable indicator of impact in aggregate terms (eg. Gläser & Laudel, 2007; Antony van Raan, 1996; Anthony Van Raan, 1998). Citation data has been used in the innovation literature and often it has been referred to as an indicator of research quality. It is important to note that while the number of citations a publication receives does measure the number of times other publications refer to it, is cannot be used as an indicator of quality (Martin & Irvine, 1983). While an argument can be made that high quality research or breakthrough research often is cited frequently, there are many other reasons why research is cited and there are large field differences in citing behaviour. Therefore, I refer to citations as indicators of impact (Garfield, 1963). Impact is understood as *the influence on surrounding research activities at a given time* (Martin & Irvine, 1983, p. 70). Importantly impact cannot be equated with quality nor importance and citations are merely indicators (not measures) of impact. Some may go as far to say that citations only indicate the visibility of research. More important is the fact that citation rates of publications vary considerably depending on the field of science. Therefore, studies that use raw citation counts to analyse differences in impact have a large source of bias (L. Waltman & N. J. van Eck, 2013). In this dissertation, I only use field normalized indicators which to a large degree control for the different citation rates within different fields and ensures that citation counts are relatively comparable among different types of publications.

Analyses of impact rely in particular on two indicators, the mean normalized citation score (MNCS) and the proportion of publications among the 10% most cited within the same field and year (PPtop10%). Such relative indicators are needed here because the typical number of citations is highly dependent on research field, publication type and the time allowed before citations are counted.

3.3.2 Project Data

In chapters 5 and 6, I exploit a contract database, *Inteum*, from the Technology Transfer office (TTO), Aarhus University. Inteum is a contract management tool used in the TTO. The database contains documentation of all projects performed by university employees, which involves external third parties. The primary documents stored in the database are project descriptions, budgets, contracts and funding agreements. The access to the database is under certain constraints due to concerns about confidentiality. The access includes all completed projects with participation of employees at the faculty of Science and Technology categorized as collaboration agreements, EU Agreements and sponsored research agreements. Due to proprietary and confidentiality concerns, access excluded non-disclosure agreements and material transfer agreements as well as technology licensing agreements. Inteum is a valuable source of detailed information on a varied sample of university-industry projects, sufficiently large to perform quantitative analyses on. Earlier work on knowledge production and dissemination have relied on either qualitative interviews or surveys to elicit sufficient information on projects (Angela McCabe, Rachel Parker, & Stephen Cox, 2016; M. Perkmann & Walsh, 2009). Interviews have the drawback of resulting in a low number of observations and potential issues of recollection bias. Surveys of academics provide large amounts of data but significantly less detail. For example, surveys rarely link projects directly to project related outputs. Project data related to specific funding instruments, which has similar benefits to the project data in this dissertation, has the downside that there is less variation in the types of projects, and that results likely reflect the design of the specific funding instrument used to elicit the information.

3.3.4 Dataset development for Chapter 5

In this section, I describe how the dataset used in chapter 5 is set-up and specifically how projects are classified in terms of objective and how projects were linked to project-related publications.

Chapter 5 analyses a sample of 117 university-industry projects selected from the inteum database. In the database, I selected all projects involving at least one firm that were initiated between 2010 and 2014 and where projects were set to finish before 2018. In order to perform analyses of the projects, some information is necessary. Therefore, I excluded all projects that did not have a project description, contract and/or budget. Finally, I did not consider projects that involved more than 12 organizations. This was mainly due to the extreme difficulty in handling the complexity in coding when projects grew in the number of participants.

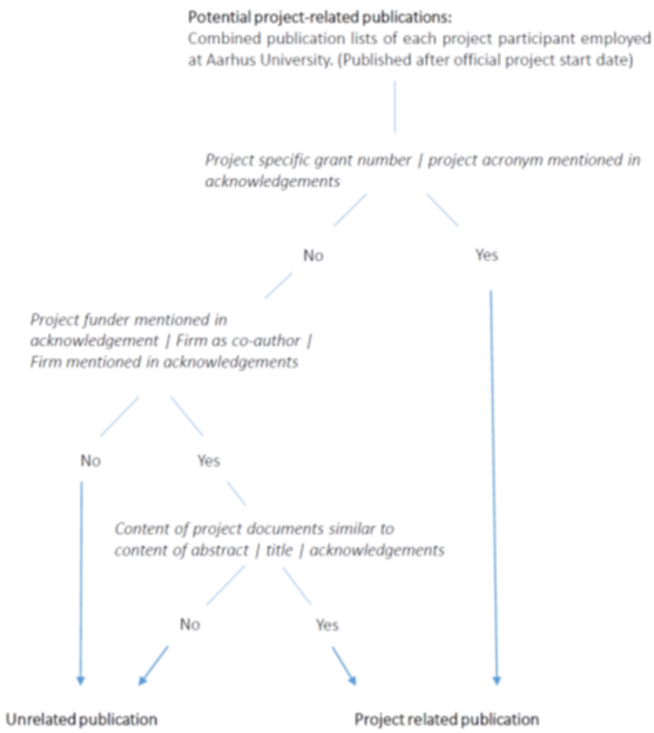
In total, 219 projects with industry participation where initiated between 2010 and 2014, ended prior to DEC 2017 and had less than 13 organizations. In total, 117 university-industry met the criteria while 102 projects did not have sufficient information and were not coded as a result. The majority of the projects that did not have enough information where projects initiated in 2010 or 2011 (43). The main missing data was sufficient project descriptions and budgets. Since project descriptions and budgets where missing, it is not possible to provide any detail on what type of projects where not selected. The number of participating organisations ranges between 2 and 13 with a maximum of nine firms and seven universities. 47 percent of projects are dyadic consisting of an AU employee and a firm. 26 percent consist of two or more firms and two or more research organisations. 13 percent consist of Aarhus university and two or mare firms and finally 14 percent of the projects consist of one firm and two or more universities including Aarhus university.

The number of researchers from Aarhus University ranges from one to sixteen researchers. The number of company and other research organisation researchers was not recorded as it was only possible to consistently record Aarhus university researchers from the available documentation. All named Aarhus University researchers were recorded by name, department, e-mail and academic position. Academics were affiliated to The Department of Engineering in 30 % of the projects, The Department of Food Science in 16 % of the Projects, The department of Molecular Biology in 14 %, The interdisciplinary nanoscience centre in 14 %, The department of Animal Science in 14 % and the Department of Agroecology in 8 % of the projects. The departments that were less represented in the sample include Department of Mathematics (0%), Department of Physics and Astronomy (2%), Department of biology (3%), Department of Environmental Sciences (3%), Department of Geology (4 %), and Department of Computer Science (5 %) and Department of Chemistry (7 %) The average budget of a university-industry project is DKK 9.8 m. and ranges from the smallest budget of DKK 25.000 to the largest of DKK 60.5 m.

For each project, I read the newest versions of all relevant project documents (contracts between project parties, funding agreements between project participants and funding agencies, budgets, and project descriptions). The purpose of this was to 1) code pre-defined variables, 2) identify necessary information for linking projects to project-related publications, and 3) identify paragraphs that describe the objectives and tasks of the project. The pre-defined variables include the budget size in DKK, the budgeted tasks of academics and firms, the proportion of the budget funded by firms, university partners and external funders, as well as how firms fund (in-kind or in-cash) the duration of the project, the number of firms and research organizations. The necessary information used in the linking of projects to publications included the names, addresses and emails of AU academics, the names and addresses of firms, the name of a potential funding agency, including potential grant names, acronyms and ids, and finally paragraphs describing the objectives and intended outcomes of the project.

Linking projects to the publications that are directly related is challenging for a number of reasons. Project participants, especially academics, continuously publish in international peer-reviewed journals from a myriad of different projects. Simply identifying all publications published by project participants in a period after a project has been initiated would include an extreme amount of false positives. I therefore, devised a method that could identify publications that are highly likely to be outcomes from a specific project. In total, 418 project-related publications for 117 projects were identified using the method illustrated below:

Figure 1: Identification and selection strategy for project-related publications



As a first step, I compiled a list of publications for each academic involved in a specific project using the author disambiguation algorithm in the CWTS enhanced version of the Web of Science database (Caron, E. & van Eck, N.J. 2014). Full names and e-mails of were used to identify publication lists. For practical purposes, publication lists were based only on researchers from Aarhus University. This means that any project-related publications that do not include at least one co-author from Aarhus University are not included.

Second, for each project, I batch search the list of potential project-related publications in the web-based version of Web of Science and select publications that satisfy a set of inclusion criteria, described below. Each publication positively identified as a project related publication is recorded with identification number and the inclusion criteria that applies to the publication.

Publications are considered directly linked to the project in question when the authors acknowledge the particular project by name, acronym and/ or grant number in the acknowledgements of the publication. Publications that do not satisfy this criteria are classified as project-related publications when the funder or firm(s) is mentioned in the acknowledgements, or the firm(s) is a co-author *and* the content of the publications' abstract, acknowledgements and title are similar to the content of the project description, or in other ways points to a direct link between the project and publication. In some cases, authors may shorthand acknowledgements without mentioning any specific project but only the funding agency or private funder. In these cases, publications may be related to a project funded by the same funder but in a different project initiated earlier, simultaneously or later. In order to ensure that these publications are not included as project-related publications I manually compare the abstract of the publication with the project description and disqualify publications that thematically are different from the project description.

Classifying projects in terms of their objective

I classify the 117 university-industry projects in terms of their objective informed by the typology developed by M. Perkmann and Walsh (2009) that include four types of projects placed on a "finalization" continuum. I operationalize the four types into mutually exclusive categories in order to be able to code each project consistently Table 1 contains the definitions and coding criteria used, along with the descriptions of the types from the Perkmann and Walsh (2009) study).

Table 1: Definitions and coding criteria

Project type	Definition	Coding criteria	Perkmann and Walsh description of ideal type	Perkmann and Walsh explication
Problem solving	The project aims to provide advice or a solution to a limited and clearly specified problem related to a company's existing product, process, machinery, equipment or ongoing R&D activities.	The project revolves around (one or more) companies' existing products, processes or concepts that are on or close to the market or parts of the firms machinery and equipment. The project objectives and tasks focused on solving or providing advice for solving a problem/challenge for the firm or the researchers provide a clearly specified service for a firm	*Providing advice regarding technical problems arising within a firm's R&D, manufacturing or other operations*	*The projects involved products, processes or concepts that were either close to market or already on the market, or parts of firms' machinery and equipment. Therefore, the projects were characterized by low degree of technological or scientific uncertainty as the requirements were strictly defined by the problems to be resolved.*
Technology development	The project aims to develop a new or improve an existing product, process, technology or concept relevant to the participating firm(s).	The project attempts to develop a new or significantly improve or alter a product, process, technology, or other parts of the firms operations.	*Developing design specifications or prototypes for new or improved products or processes*	*Often such projects resembled conventional, formally established academic research projects although substantially they pursued proprietary technology development. These projects dealt with concepts, products or processes, which, compared to problem solving projects, were a step removed from "market readiness". They were afflicted by relatively higher degrees of uncertainty as only general requirements were known, while the actual problems to be resolved were not tightly specified ex ante.*

Ideas testing	The project aims to explore the theoretical and technical feasibility of a potentially commercially interesting idea or ideas	The project focuses on exploring a potentially commercially interesting idea (s) that is not yet translated into a concrete concept, prototype or technology. This will often be in the form of feasibility studies or experimentation.	*Exploring a high-risk concept on behalf of a firm – outside the firm's mainstream activities*	*These projects sometimes built on concepts and technologies developed by academics which they "sold" to firms to pursue tentative exploration of their application potential. In other cases, specific ideas had emerged within firms' R&D or manufacturing units and the firms had approached the academics to explore these ideas because they were seen as having the required expertise.*
Knowledge generation	The project aims to examine a hypothesis, to understand a process, the characteristics of a phenomenon, or relationship within a field with only limited reference to and activity towards commercial application.	The project examines a hypothesis, process, characteristics of a phenomenon, or relationship within a field with only limited reference to commercial application.	*Carrying out research on topics of broad interest to a firm*	*… consisted essentially of academic research projects with industry participation. These projects in most cases were initiated by academic researchers. The objectives of these projects tended to be informed by the challenges arising at the frontier of academic research.*

I followed a three-step coding procedure. First, I identified paragraphs in the project documents that described the objective and tasks of the projects. Second, I produced a summary (approximately 4-10 sentences) and an abstract form of the project (1-3 sentences) of the project based on the text (See table 2 for examples). The first summary was for analytical purposes where I coded as close to the original phrasing as possible. The abstract form removed all information that may be used to identify the project as I am under an agreement of confidentiality. Finally, based on my operationalization of Perkmann and Walsh's (2009) typology I coded each project as one of the four types. In table 2 – the condensations of each project are listed below the project to which they are classified.

Defining when a project is more or less finalized on the basis of a project description and contract requires translation of finalization to practical and specific parameters. The primary challenge is to consistently categorize projects that differ on a large number of other parameters. Projects have a varying number of project patterns, focus on different areas of research and in different industries.

Project descriptions no matter the heterogeneity contain specific elements that can inform categorizations based on the concept of finalization. Every project states the aim of the project, it defines some problem area or state of development, it defines the tasks of the project partners.

Choosing specific and categorical rules for categorizing projects on a finalization dimension would be an impossible task. Therefore, the approach taken in the chapter is to define broad-based qualitative criteria and descriptions of project types. The coding task is evaluative and subjective. Categorizing projects is a task of evaluating whether the aim of the project fits with the description and criteria defined for a specific category.

This provides a degree of uncertainty because the evaluation depends on the coder's interpretation of both the description and criteria for each category as well as the interpretation of the project description. In order to minimize inconsistencies the coding procedure is accompanied by the act of writing an argument for the chosen category – why it fits with a certain category definition and lives up to the criteria as well as an ex ante review of the internal consistency of projects categorized under each category ex ante.

An optimal approach would be to have multiple coders. This would enable an analysis of intercoder reliability and evaluate the adequacy of the definitions and criteria as well as highlight the projects may not fit the theoretical categorization. However, this approach is not viable as the access to the contract database is limited to the author of this article.

The method chosen therefore puts a high level of responsibility on the author to provide as much detailed information as possible for readers to assess the consistency and trustworthiness of the material. I do so by providing a number of detailed examples of projects alongside descriptions of why and how they were coded. These descriptions can be found in table 2. Because of the sensitive nature of the material and the legal repercussions of sharing information, these descriptions involve simplifying and censoring some information. The classification reasoning provides an understanding of the complexity in categorizing projects in four pre-determined groups.

Table 2: Examples of categorization procedure

Abstract (redacted)	Condensation	Classification reasoning	Coding
	Develop diagnostic test for use in company	The project attempts to develop a method for testing for pregnancy disorders. The main task is to test and develop an already described and developed concept in publications and patent applications. Therefore, it is a technology development project.	Technology development
	Develop ventilation system for pigsties that improves air quality	It is not ideas testing, because the idea is set, the main aim is to achieve a fully functioning prototype. It is not entirely clear which stage they are in at the time of initiation. It is written as if they have the concept in place and need to develop further and demonstrate on a test facility that the concept works. There is a degree of uncertainty of the project, yet the technical specifications are known. Therefore, it is not an ideas testing project, which is more uncertain and has less specificity.	Technology development
	Perform specialized analyses of newly developed drug	The development of the drug depends on the results. The researchers thus provide the company with information and knowledge that can aid them in their R&D. While the technological stage is still in development, the aim of the project is to provide a well-defined service for the company.	Problem solving
	Investigate feasibility of Integrating ICT into the heard management and production process of growing pigs	The project is ideas testing because it focuses on an idea that introducing ICT into herd management will be able to improve animal welfare. Yet, the exact processes and possible technological results are not known. The results from the project can lead to technology generation projects based on more specified ideas at a later stage.	Ideas testing
	Use of hydrogen as a carrier of renewable energy for transportation using high pressure storage tanks	The project is a high-risk project detached from application. If successful there will be patenting and a plan for commercialization and development which will be still years from implementation. The company involved is specialized within hydrogen pre-cooling and refuelling and can therefore find uses for a successful and useable concept.	Ideas testing

	Investigate through genetics research how to prevent epidemics caused by yellow rust in plants.	It is a knowledge generation project, because it attempts to understand the mechanisms and genetics of rust development. However, there is an application focus for the involved company that will be able to include results in their breeding programme at a later stage. It is not ideas testing, because they do not have an idea of what possible solutions could be but rather within an overall framework of genetics. Furthermore, the "applied" part is a very small part of the project that is contingent on the research findings.	Knowledge generation
	Testing the nutritional quality and sensory effects on milk of utilizing bi-products from bio-ethanol production as feedstuff for animals.	This is a very difficult project to classify within one of the four types. On the one hand, the project takes departure from the problem that a lot of milk is discarded because of taste problems, which is often accredited to the use of bi-products as feed-stuff. The project attempts to find causes of the taste problem. On the other hand, the project attempts to create knowledge of how to optimize the use of bi-products in feedstuffs. This can be an ideas testing or knowledge generation project - because they are attempting to produce actionable knowledge that is both relevant for broadly in the scientific community as well for the practical use for companies. Since the knowledge will be able to used as inputs to the companies development choices later on I code it as knowledge generation, because a concept for using the potential knowledge outcome does not exist.	Knowledge generation
	Testing the hypothesis that extended lactation periods combined with targeted feeding can improve milk yield.	The project arises from scientific findings, yet they have not yet been tested in practice, thus it is a knowledge generation project. One could argue that the project also has ideas testing elements, yet the project focuses mainly on testing different aspects of the overall hypothesis. Rather than testing one specific idea or concept. The project resembles a typical research project with hypotheses and planned tests. And the outcome is very uncertain.	Knowledge generation

Note: The table includes eight examples of the coding procedure performed on 117 projects. The text has been altered from the original coded material as to maintain confidentiality. Moreover, full abstract from descriptions of projects are redacted entirely. The text thus only resembles the original material used for categorizations.

3.3.5 Dataset development for Chapter 6

Chapter 6 utilizes information from the dataset developed for chapter 5 and combines it with detailed bibliometric information on the publications published by academics who were engaged in one or more of the 117 projects. 219 academics participated in the 117 projects. In order to conduct the analysis, I require that academics have published at least one university-industry project-related publication (industry publication) and at least four other publications (portfolio publications). A significant number of academics either did not author a project-related publication, or due to their seniority level did not have a large publication record. Therefore, the selection strategy yielded a sample of 115 out of 219 academics for this study.

The unit of analysis in the study is publication pairs. I analyse the degree of similarity between an academic's industry and portfolio publications (industry-portfolio pair) compared to the similarity of portfolio publications (portfolio pairs). If research within university-industry projects is similar to the research that academics generally pursue, then the expectation is that the average similarity between industry-portfolio pairs will be equal to the average similarity between portfolio publication pairs. The database consists of variables that describe the relation between each pairing of publications authored by a particular academic. The database in total consists of 746,625 publication pairs for 115 academics.

I calculate cosine similarity between two publications based on titles and abstracts. I process the text data (titles and abstracts) by first removing stopwords and then by stemming terms so that terms such as "probability" and "probabilities" are treated as one term "probabil*". Based on the reduced and stemmed term list, I construct a document-term matrix that counts the number of occurrences of a term in a document. The cosine similarity between two documents is calculated based on the degree of co-occurrence of the same terms. Each term in the abstracts is notionally assigned a different dimension and an abstract is characterized by a vector where the value in each dimension corresponds to the number of times the term appears in the document. Cosine similarity provides a useful measure of how similar two documents, based on their abstracts and titles are likely to be in terms of their subject matter.

In addition to cosine similarity based on text, I calculate similarity in terms of bibliographic coupling. Bibliographic coupling occurs when two works reference a common third work in their bibliographies. Two documents are bibliographically coupled if they both cite one or more of the same documents. A high level of bibliographic coupling is an indication that two works treat a related subject matter. While the interpretation of bibliographic coupling is quite intuitive, a bibliographic coupling is merely an indication of the existence of the probability, value unknown, of a relationship between two documents rather than a constant unit of similarity (Martyn, 1964). Thus, the co-occurrence of a reference may indicate different levels of similarity depending on the reference and context. Bibliographic coupling is similar to text similarity, where it is the co-occurrence of references instead of terms that are of interest. Cosine similarity provides an indication of how similar the two documents are in terms of their knowledge bases.

Challenges of this type of design are that of assigning context to a publication. I argue that we get close to dividing publications into two groups, those published in an academic environment and those in the context of interaction with firms. However, in the chapter, I perform various robustness checks. Another main challenge is the extent to which cosine similarity of text and bibliographic coupling can discriminate on the intended parameters. There is a risk that differences are not captured to the full extent and that some are exaggerated. In the discussion of the chapter, I attempt to visit this question by visualizing differences using alternative measures of similarity and comparing to the measures applied in the main part of the chapter.

3.3.6 Dataset development for Chapter 7

In this section, I provide a more detailed description of how the dataset for the analysis in chapter 7 is set-up and specifically how we identify publications that are co-authored by industry. Moreover, I describe how the data for the two main analyses was organized and curated.

The dataset covers 189,703 journal articles covered in the Web of science (WoS) with at least one Danish address published over the period 1995-2013. Identifying scientific outputs from university-industry collaboration at a large scale is a difficult task, which we attempt to do in the chapter. In chapter 7, we assume that publications co-authored between an academic and a researcher affiliated to a firm, results from some degree of collaboration. Based on this assumption, we classified each affiliation (text that denotes the address and organisation of a co-author of a publication) of publications in the sample to identify all publications that had an author affiliated to a Danish or foreign firm, or to a Danish or foreign public research organisation. Using this information, we could create variables denoting five mutually exclusive publication types: National public research, international public research, national public-private research, international public-private and industrial research.

We combined indicators available in the CWTS in-house version of Web of science with manual validation and classification of all Danish addresses in the dataset. The CWTS in-house version of WoS contains indicators of whether publications include an author from private industry, and whether the publication includes authors from two or more different countries. We enhance this data in order to create the more detailed types listed above. For all non-Danish addresses, we assumed that the indicators were sufficiently accurate in terms of whether an author from private industry was involved and whether the article had authors from a country apart from Denmark.

We employed a rule-based algorithm that classifies all Danish addresses as either public research institutions, private businesses or other public organisations. First, all affiliations were classified if they contained text that identified the type of organisation. An affiliation would be classifies as a university if it included the word "university" and an affiliation would be classified as a private business if it contained a "inc", "ltd", "gmbh", "AS" etc. We took into account different spellings and misspelling of terms. We considered multinational firms and corporations with addresses in Denmark as Danish private firms, when the affiliation of the article referred to their Danish address. All remaining affiliations were classified manually by multiple coders. All privately owned organisations (including consultancies) where classified as private business with the exception of national research institutes. Individuals were classified as "other". Unknown organisation names that could not be matched in the business registry nor matched any known public research organisations where disregarded in the analysis. In total 6133 Danish organisation names where coded by comparing them to the Danish business registry.

Based on the described methodology we could classify publications in terms of their type of collaboration. We use this classification in two ways, first we analyse the citation impact of the five different types of publications, taking into account potentially confounding factors. Secondly, we perform an analysis at the level of the academic. For a sample of 747 Danish authors, who had published articles classified in each of the types (with the exception of industrial research), we analysed whether the citation impact differed on average depending on the type of publication while controlling for variation at the level of the academic.

Chapter 4: How is the publication decision determined in university-industry projects?

University-industry collaboration is argued to benefit society through greater innovation and alignment between science and society (Mansfield, 1998; Salter & Martin, 2001) and to provide benefits to academic research (Dutrenit, De Fuentes, & Torres, 2010; Garcia, Araújo, Mascarini, Santos, & Costa, 2020). Science and innovation policy in Denmark, as in many other countries (Geuna, 2001; Mowery & Sampat, 2004), has focused on fostering interaction between academics and industrial actors (Aagaard, 2012). This agenda has been supported by arguments that such interactions lead to more and better innovation while going hand-in-hand with impactful scientific research (Styrelsen for Forskning og Innovation, 2015). However, there may be costs and unintended consequences to increased interaction, including that relevant research goes unpublished or is significantly delayed (Behrens & Gray, 2001; Geuna, 2001; Slaughter & Leslie, 2001).

Empirical evidence suggests that academic engagement in university-industry collaboration is generally found to be complementary to academic research when measuring the publication activity of academics engaged with industry (Markus Perkmann, Salandra, Tartari, McKelvey, & Hughes, 2021). Engaged academics on average sustain high levels of productivity compared to their peers (Landry, Traore, & Godin, 1996). However, evidence also suggests that academics involved with industry are more likely to engage in secretive behavior including postponing or foregoing publication of publishable research (Blumenthal, Campbell, Causino, & Louis, 1996). Moreover, in collaborative projects, academics and firms often experience conflicts related to the different objectives and incentive structures of science and industry (Crespo & Dridi, 2007; McCabe, Parker, & Cox, 2016). Empirical knowledge is lacking with regards to when and under which circumstances knowledge produced within university-industry collaborations are shared within the scientific community through scientific publication and when knowledge is protected through secrecy and goes unpublished. Moreover, we have little theoretical understanding of which factors may influence the decision to disclose knowledge. Based on empirical studies, scholars argue that the defining factor to whether knowledge is shared and published is the degree to which knowledge is commercially relevant (D'Este & Perkmann, 2011; M. Perkmann

& Walsh, 2009). The basic argument is that projects that focus on commercial objectives rarely lead to relevant scientific knowledge and therefore to the publication of knowledge outcomes. Projects that focus on traditional research objectives often lead to relevant scientific knowledge and publication as this type of project rarely leads to commercially actionable knowledge outcomes that could cause conflicts. In projects that lead to both commercially and academically relevant knowledge outcomes however, relevant scientific knowledge is less likely to be published due to secrecy issues. Secrecy issues imply that firm and academic partners will both derive utility from two opposing options, secrecy and disclosure (M. Perkmann & Walsh, 2009). Yet, no conceptual explanation aids in understanding when these secrecy issues affect the publication of knowledge, and when they do not.

In light of a political agenda of increasing interaction between academics and industry and a general scholarly consensus that interaction is conducive to academic knowledge production (Markus Perkmann et al., 2021), it is imperative to understand which factors are relevant to the decision to withhold or publish knowledge outcomes in university-industry projects. When there is a conflict regarding dissemination of knowledge, which are the important factors that influence whether project partners decide to publish or engage in secrecy to protect knowledge?Understanding this can aid in identifying the type of interactions that may lead to the privatization of knowledge that would potentially have societal and scientific value if shared. This chapter examines the question of how is the publication decision are determined in university-industry projects.

The chapter builds a conceptual framework for understanding when we would expect project partners to have conflicting preferences concerning publishing, and importantly, how a publication decision is reached in cases of apparent conflicting preferences. This theoretical chapter approaches the question within the framework of the economics of science. It utilizes empirical and theoretical literature from various fields that have investigated university-industry interaction, including economics of innovation, technology transfer and research policy.

The chapter begins by discussing from the point of view of the economics of science, how firms and academics derive benefits from knowledge production within the science system and in the market. Secondly, it suggests three factors that may affect the dissemination decision within university-industry projects: the commercial and scientific relevance or expected value of knowledge outcomes, the contractual division of intellectual property rights, and finally, the type and perceived value of the collaborators' partnership. I conclude by presenting a conceptual model of how project partners reach a decision regarding the dissemination strategy dependent on the three proposed factors. Finally, I discuss the implications and limitations of the conceptual model.

Dissemination of knowledge in the realm of science

The production and subsequent publication of knowledge claims is traditionally one of the core missions of academics along with teaching. In many respects, what characterizes academics are their focus on pursuing research questions using scientific methodology and the subsequent publication of such knowledge shared with and reviewed by colleagues (J. Ziman, 2000). Promotion and tenure as well as compensation depend highly on the amount of publications an academic has published. In many countries higher education institutions and public research organizations receive government funding based on publications and in some cases academics receive direct cash bonuses based on their publications in certain journals (Franzoni, Scellato, & Stephan, 2011).Moreover the labor market for academics entails that highly productive faculty often increase their salaries by receiving offers from alternative institutions. (Stephan & Levin, 2001).Academics face strong incentives to publish. The incentive to publish has been described both by sociologists in terms of how institutional norms promote "good" behavior and by economists in terms of how publishing is tied to economic rewards that in turn guide behavior. Merton (1969) argued that the reward system of science incentivizes academics to publish research findings in academic literature and to do so rapidly through the mechanism of "priority of discovery" (Merton, 1969). In order to gain reputation in the scientific system, individuals must be the first to stake their claim of discovery by openly sharing their scientific claims. Importantly, only the first to stake their claim is awarded "reputation"[1] (Merton, 1957). Therefore, not only is there an incentive to openly share and publish research findings and developments, but to do it in a timely fashion. Priority of discovery is also central in the theoretical approach within economics of science (Stephan, 1996). The fundamental currency in science is the "reputation gained by individuals *for 'contributions' acknowledged within his or her collegiate reference groups"* (Dasgupta & David, 1994). Unlocking the potential to reputational rewards requires sharing findings with colleagues, academics do so by publishing research findings by preparing a manuscript,

[1] The assumption that only the first to publish can gain reputation from a discovery or knowledge claim has however been rightfully criticized as replication studies and additional studies also provide value to the scientific system. Therefore, instead of describing the scientific contests as "winner-takes-all" others have described it as "winner takes most" (Dasgupta & David, 1994).

which is submitted to a journal where peers review the content (Stephan, 2004).

Although, academics face the incentives and possibly moral pressures to publish academics do choose not to publish and to engage in secretive and "anti-social" behavior (Eisenberg, 1987). In the sociology of science such behavior has been described and explained by Mitroff (1974) and J. M. Ziman (1994) in terms of counter norms or post-academic science that offer a different understanding of the normative structures of science relative to that described by Merton. They argue in different ways, that norms such as communism are not necessarily universal ideals academics attempt to follow but depend on the context, such that researchers may adhere to different norm sets in different contexts.

From an economic standpoint engagement in secrecy and secretive behavior has been described by the competitive nature of science which may incentivize secrecy to monopolize on research areas by withholding data and methodologies from colleagues (Stephan, 1996). Moreover, market-based rewards that require secrecy may outweigh the rewards related to publication. Eisenberg (1987) argues that secretive behavior is more common among academics than might initially be presumed because they can publish results and at the same time keep certain aspects of their research. Maintaining some knowledge uncodified can provide academics with competitive advantages in scientific races (Stephan, 1996). Examples include withholding developments on scientific techniques and datasets from colleagues or selectively publishing research findings while monopolizing other elements with the hope of realizing future returns.Patenting, which requires secrecy prior to filing and often may not involve the same intent in terms of communication of knowledge, is also an increasingly common activity in science (Larsen, 2011). Motivations for patenting scientific discoveries and innovations may be monetary, however, patenting and commercialization activities are also becoming a growing part of the reward structures in the higher education system (Stephan 2012). National legal frameworks incentivize or require academics to seek commercial utilization of scientific findings. Moreover, research organizations in which academics are employed are increasingly incentivizing academics to disclose any potential patentable inventions and seek patent protection prior to publishing ("Bekendtgørelse af lov om opfindelser ved offentlige forskningsinstitutioner," 1999; Mowery & Sampat, 2004). Within some disciplines, however, commercial and entrepreneurial activities can be seen as violating the norm of communism and thus may not provide reputational benefits and may instead incur reputational costs to academics (Merton, 1969; Mitroff, 1974).

Based on the discussion above I expect that academics actively pursue the publication of knowledge claims as to derive benefits from their work and enable them to secure tenure, funding and resources for future research activities. However, academics may also engage in commercial or strategic behavior that entails secrecy rather than openness, as it can provide them with monetary benefits as well as competitive advantages within the scientific system. While I base this argument on an economic and utilitarian perspective where publication behavior is based on the expected rewards or utility derived from either publishing or secrecy, a similar theoretical argument can be found in the sociology of science where behavior instead is explained by the normative structures of science.

Dissemination of knowledge in the realm of industry

Decision making in industry is driven mainly by a commercial logic where firms undertake research and development projects that have an expected rate of return that is higher than alternative investments (Rosenberg, 1990). The properties of knowledge as a public good leads to an underinvestment in research in the private market (Dasgupta & David, 1994). However, firms do undertake both risky long-term strategic research as well as short-term application oriented research and development (Rosenberg, 1990). Maximizing returns to investment in research and innovation activities often require patenting or secrecy. By protecting commercially valuable knowledge, firms can maintain a competitive advantage, whereas disclosure of knowledge may shorten the period where firms can extract above normal rents from their inventions. However, firms do engage in research even if there are many benefits that they may not be able to protect. "*Even if a firm's basic research generated many benefits that it could not appropriate, the mere existence of such non-appropriabilities is never an adequate explanation for the reluctance to perform basic research. All that is necessary is that market forces allow the firm to capture enough of these benefits to yield a high rate of return on its own investment in basic research*" (Rosenberg, 1990, p. 167). Firms may purposefully codify knowledge and file for property protection. While this means providing potential competitors access to knowledge it provides the owner of the patent the property rights to the knowledge. Firms are able through this construction to profit from inventions without secrecy. Moreover, it allows firms to engage in selling or licensing knowledge to other parties (Rockett, 2010). In addition to formal options (e.g. patenting and trademarking), firms can employ strategies to protect knowledge assets even though they eventually become available to competitors (Harhoff, Henkel, & von Hippel, 2003; Rosenberg, 1990). Patenting is costly, especially for firms that do not have the internal capacity and experience to file for patents. Moreover, patenting is not always possible if inventions do not fulfil the formal requirements (Rockett, 2010).In situations where patent protection is not a viable option and knowledge is disclosed, purposefully or not, firms can still appropriate sufficient rents from knowledge. First-mover advantages where firms are able to get to market before the competitors can secure a strong market position (Robinson, Kalyanaram, & Urban, 1994). This advantage is more likely to be profitable when the costs to imitation are high, either through material investments or because tacit knowledge is needed to fully exploit the codified knowledge. Similarly, when firms have a large market share the benefits of an innovation, even if shared with competitors, can benefit the investing firm disproportionately (Rosenberg, 1990). Finally, firms may be able to appropriate rents from tacit knowledge in the form of the skills and experiences that are built up during the research process (Rockett, 2010). In some cases, publishing research is a deliberate strategy by firms in an attempt to protect from potential competition. In fact, publishing can be used as a strategy to deter competitors from entering the market (Harhoff et al., 2003; HICKS, 1995; Li, Youtie, & Shapira, 2015).

Firms engage in research activities internally and in collaboration with other organizations for a variety of reasons (Bayona, Garcia-Marco, & Huerta, 2001; Teece, 2010). While generating valuable knowledge and innovations can be an obvious motivation, firms also engage in research with academics in order to maximize possibilities of gaining public procurement contracts and building a knowledge and skill base internally (Cockburn & Henderson, 1998). The disclosure of potentially valuable knowledge may in some instances be a calculated cost of gaining access to the knowledge and skills of academics (W. M. Cohen & Levinthal, 1989). Thus, deriving returns from investments in research projects, does not have to entail appropriation and privatization of knowledge. It may in many instances be a deliberate strategy to pursue open science as a private company (Laursen & Salter, 2014). The concepts absorptive capacity and related connectedness are often applied to explain the reasoning of firms' engaging in open science activities which have no apparent or immediate economic pay-off (Cockburn and Henderson 1998). Being active in the science community can be a prerequisite in many industries to be able to recognize and take advantage of developments in science and actively engaging in open science practices such as publishing can allow firms "to engage in the barter-governed exchange of scientific and technical knowledge" (HICKS, 1995). Firms may in some cases value an increase in absorptive capacity and connectedness as the core benefit from their investment in research projects. However, while the intention of a firm may be to engage in open science for the purpose of building absorptive capacity and connectedness with the scientific community, that does not necessarily mean firms will automatically forego obvious commercial opportunities when knowledge has been produced and the expected benefits of secrecy versus openness are "known". Thus, concepts such as absorptive capacity aid in understanding why firms may engage in collaborative projects with seemingly uncertain outcomes of a low expected commercial value – Yet this type of motivation or strategy does not mean that firms will forego commercial opportunities, through knowledge protection, when they arise.

The reward structure of the market overall incentivizes firms to protect knowledge. However, when the option of secrecy or patenting is too costly or is unavailable, firms can still appropriate rents from their investments. Moreover, engaging in publishing may provide benefits in terms of employee retention, reputation and relationships. Additionally, participation in research and development with external partners may be motivated by a strategic interest in building absorptive capacity and connectedness to the scientific community. Accepting a lower return on investment through appropriation may in some cases be a calculated cost of doing business and being able to maintain a good relationship with academic collaborators.

The dissemination decision in university-industry projects

> [...] what fundamentally distinguishes the two communities of researchers is not their methods of inquiry, nor the nature of the knowledge obtained, nor the sources of their financial support. To be sure, differentiations between can be drawn along those lines, [...]. It is the nature of the goals accepted as legitimate within the two communities of researchers, the norms of behavior especially in regard to the disclosure of knowledge, and the features of the reward systems that constitute the fundamental structural differences between the pursuit of knowledge undertaken in the realm of Technology and the conduct of essentially the same inquiries under the auspices of the Republic of Science (Dasgupta & David, 1994, p. 495)

The decision regarding disclosure of knowledge within industry and academia are driven by distinct and different reward systems (Dasgupta & David, 1994). When collaborators in the two realms produce knowledge together, the preferences for disclosure and secrecy potentially can diverge and cause conflict. The following sections attempt to provide a conceptual framing for understanding the decision of knowledge disclosure in university-industry projects.

For the purpose of clarity, I define what I mean by university-industry projects throughout this chapter. University-industry projects are university-industry collaborations delimited by an overall objective, deliverables, sets of task, timeframe and budgets. In comparison, university-industry collaboration refers to the transfer, exchange or co-creation of knowledge or technology between researchers and private market actors. University-industry projects thus include projects funded by firms and performed by academics such as consultancy, contracted and sponsored research as well as co-funded or externally funded projects where tasks are performed jointly by academics and firms. The requirement that an objective, deliverables, tasks, timeframe and budgets are defined mean that informal and non-contractual interactions are not included.

How partners in a university-industry project decide on whether or not and how to disseminate co-produced knowledge depends on the type of knowledge that is produced and the potential costs and benefits dissemination or secrecy entail for each partner. Moreover, the design of the project contract will likely affect the options each partner has. Finally, the characteristics of the partnership between the academic and firm factors into the decision. In this section, I argue why these three aspects are important for understanding the dissemination decision. I conclude by summarizing the conceptual mode and discussing the limitations and implications of the conceptual model.

The characteristics of the knowledge outcomes

The academic relevance and commercial value of knowledge outcomes are defining parameters for the value of publication and actively investing in the protection of knowledge (M. Perkmann & Walsh, 2009). Publishable knowledge (knowledge that can be codified and communicated to academic peers) provides academics with reputational benefits within the scientific system when published and conversely opportunity costs if kept secret (Stephan, 1996). The commercial value or relevance of knowledge similarly is important for firms. Rents from knowledge outcomes that can be translated into improved or new products, services, processes are, all else equal, increased through secrecy (Rosenberg, 1990). Publishing and thus sharing this knowledge would entail an opportunity cost equal to the difference in obtained rents with and without secrecy.Thus, the type of knowledge that is produced within a university-industry project defines the cost-benefit structures for both parties in terms of secrecy and openness.

Empirically, studies have distinguished between the objectives of projects (equating the objective to the outcome). M. Perkmann and Walsh (2009) find that projects with objectives close to the market rarely lead to publication; they argue that this is because knowledge outcomes are often highly commercially relevant and rarely scientifically relevant. Knowledge generation projects tend to lead to publication because they primarily lead to academically relevant outcomes and rarely lead to commercially valuable outcomes. Projects that are instead at an intermediate distance to the market tend to produce both commercially and scientifically relevant knowledge and therefore publication of knowledge may be delayed or forgone.

Knowledge can have value in both an academic and in a commercial context simultaneously (Stokes, 1997). However, in some cases, knowledge may have very low scientific value due to the way knowledge was produced or in terms of the novelty of the findings (D'Este & Perkmann, 2011). Similarly, knowledge may have very low commercial value because it is too abstract or the partner firm does not have the capabilities to translate the knowledge into a commercially viable product or process at the time of production or discovery.

When knowledge outcomes are simultaneously commercially valuable and scientifically relevant, the utility that a firm may derive from knowledge depends on the period of time it can extract above normal rents. Withholding knowledge from actors in society may be an efficient way to ensure this. However, the same knowledge will likely provide academics with maximum utility when it is codified and published in an academic journal. Hence, If outcomes are both commercially and academically relevant, the incentives of the parties may conflict.

Legal/contractual context:

In cases of conflicting incentives, the decision of whether to pursue publishing or secrecy must depend, at least partially, on which party has the legal ownership of knowledge or has the right to decide on the strategy for co-produced knowledge. Contracting rights to future knowledge outcomes is inherently difficult since the knowledge generation process is uncertain and unpredictable (Bozeman, Fay, & Slade, 2013). Yet, rights to future knowledge outcomes are often agreed upon in broad terms prior to engagement in collaborative projects (Bercovitz & Tyler, 2014). For example, in collaborations at Aarhus University, there are several standard guidelines to how rights to foreground knowledge should be treated. Rights to foreground knowledge are either assigned to firms, academics or some form of shared ownership. When rights are shared, it may be specified that potential protections of knowledge should be performed in a timely manner that allows for subsequent publication of knowledge. This can be specified as a period of time where filing for a patent can be pursued jointly where-after academics are free to publish relevant findings. Firms may have the right to delay, review and edit potential manuscripts prior to submission. In effect, either the academic partner or the firm will have the legal right to decide on eventual publication or protection of knowledge.

Assuming that the publication decision is based on maximizing utility and the only relevant factor for is the expected benefits of knowledge with or without secrecy, the firm will likely choose secrecy of commercially relevant knowledge and academics, publication of publishable knowledge. This of course leaves out, at least, one crucial aspect: The decision of the controlling partner may incur large opportunity costs on the other partner. I argue in the next section, why the value of the partnership is an important aspect of the decision.

Partnership

Firms that have the legal contractual right to knowledge or the right to modify and delay publication can choose to impose secrecy on their academic partners. However, the long-term costs to the specific partnership may outweigh the immediate benefits from pursuing such a strategy. Similarly, academics that have a legal right to choose to publish all relevant knowledge immediately may also incur long-term relational costs. Thus, publishing may mean forfeiting future contracts with the firm and other firms in the future.

The partnership between firms and academics can have a substantial strategic value to both academics and firms (Wesley M. Cohen, Nelson, & Walsh, 2002). Academics may have long-standing partnerships with specific partners where they engage in a range of interactions (Garcia et al., 2020) . Academics may be dependent on firms for a range of resources and activities: access to instruments, facilities, compounds and funding of research, placement of students, industrial PhDs and Post docs. Similarly, firms can be dependent on academics and groups for knowledge and skills, equipment and as a general window to scientific progress (Cockburn & Henderson, 1998).

Firms that decide to impose costs on their collaborating partner may risk that the partner no longer wishes to interact in the future. Moreover, the academic partner may share their experiences with colleagues that in the future will be more hesitant to interact with the firm. Hence, this would limit the firm's access to a potentially valuable knowledge and skill base. Similarly, academics who do not attempt to accommodate their partner may forego future contracts and funding from the firm as well as other firms in the future.

The damage to the partnership and reputational cost will likely depends on the initial context of the project such as the stated objectives, division of labor and funding of a project. For example, if a project were funded by the firm with the objective of innovation and commercialization, pursuing protection of relevant knowledge outcomes would not come as a surprise to the academic party as much as it would if the project was funded through a basic research grant. Likely, the division of property rights will reflect the initial objective of the project. However, since knowledge outcomes are difficult to predict, preferences after knowledge has been produced can easily change. Importantly, the benefits of pursuing secrecy or disclosure may be so large that damage to reputation and relationships are acceptable costs.

Dissemination strategies

The dissemination decision is not simply whether to publish immediately in a peer reviewed journal or to withhold all knowledge from the light of day. Depending on the context and the characteristics of knowledge, there are a number of intermediate options where the value of knowledge can be appropriated commercially while it can also be shared publicly. Such intermediate solutions may be chosen when project partners wish to find a compromise that benefits both parties.

There are many alternative solutions that can be applied that can be seen as a compromise that provides lower benefits but also minimizes reputational and relational costs that may be important for firms and academics who wish to collaborate with each other or other actors in the future. Possible alternatives to disclosure versus secrecy are partial disclosure of knowledge, delaying disclosure of knowledge, disclosure of knowledge followed by alternative measures of protecting rents, patenting then disclosing and finally combinations of all strategies.These options may provide fewer benefits in terms of maximizing rents or reputational benefits, but do not incur long-term relational and reputational costs as the partner is accommodated. Thus, in some cases, the alternative solution will provide a preferable cost-benefit structure for the collaborating parties.

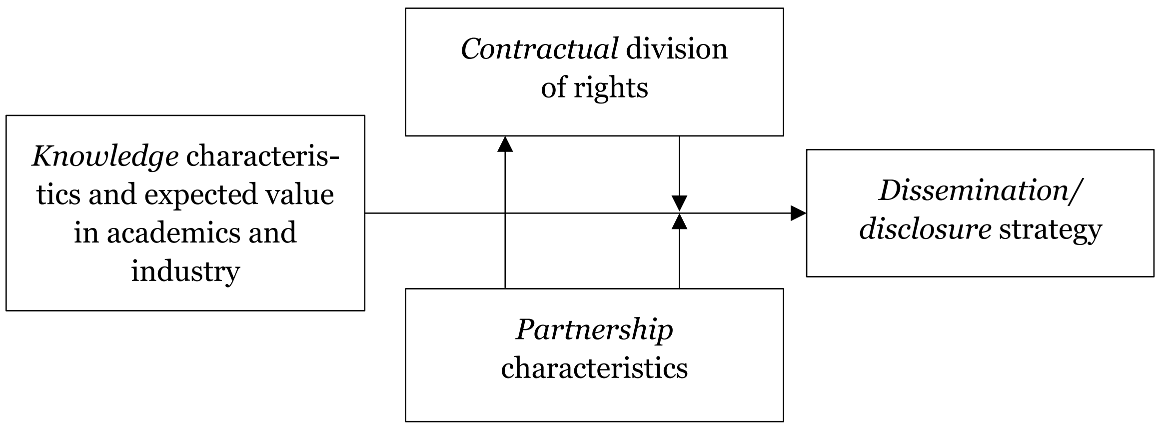
Patenting followed by publishing may be an optimal alternative in many situations. Academics delay publication and either allow firms to file for a patent or in collaboration with firms seek patent protection of inventions or scientific findings. When the patent has been filed, publication of the knowledge does not hinder protection in the patent system.

Not all knowledge that can provide firms with competitive advantages is patentable. However, maintaining competitive advantages may still depend on how well the knowledge is kept secret. Academics can in some circumstances aid in this endeavor simply by leaving some knowledge tacit and unmentioned in journal publications. Academics may decide to publish on the findings without elaborating on the method developed in order to produce such findings. Alternatively, they may only publish on some findings, while delaying or foregoing publication of other findings. In M. Perkmann and Walsh (2009) they describe a number of cases in which academics choose to delay publishing in order to accommodate their industrial partner.

Firms are able to protect knowledge through a range of mechanisms and can in some instances appropriate rents from knowledge and inventions that have been disclosed(Rosenberg, 1990). First-mover advantages may sufficient to provide firms the time to build an advantage in the market, firms can appropriate monopoly rents for a long period of time.Moreover, publication of research findings may be a strategy to signal to competitors that the firm that they should not enter (Li et al., 2015). Some firms may have a market position that enables them to capture sufficient rents from an investment even if knowledge is made available(Rosenberg, 1990).

Concluding on the conceptual model, limitation and implications

The purpose of this chapter was to conceptualize how project participants with seemingly different objectives with regards to how to exploit knowledge, decide on how and whether to disseminate co-produced knowledge. In figure 1 I illustrate the conceptual model. I argue that the chosen dissemination strategy depends on the expected value of the knowledge outcome from the perspective of the firm and academics moderated by the division of property rights and the future value of partnership and the risk that a dissemination strategy will harm the partnership.



When the firm in a university-industry project has the property right to knowledge produced in a university-industry project, they can choose secrecy or allow/participate in publishing while following an alternative strategy to protect the commercial value of the knowledge. Assuming the firm chooses the option that provides the highest expected utility, the choice between the two options depends on the expected value of the knowledge in each of the two options and the risk that the partnership is abandoned if choosing secrecy and the perceived future value of the partnership. Thus, the utility of secrecy is diminished by the expected future value of partnership with the academic and the expected probability, the partner will sever future ties given the choice of secrecy. The probability likely increases when the knowledge has scientific relevance. The larger the expected reputational gains the academics forego from firms choosing secrecy the more likely they are to sever collaborative ties. This relies on the premise that they will not wish to engage in a similar collaboration with the firm again due to the expectation that the firm will disregard their preferences.

When the academic partner has the right to knowledge produced in a university-industry project, they can choose to publishing or to accommodating firms wish for secrecy by for example delaying publishing or selective publishing – allowing firms time to gain first mover advantages, or academics may file for patent protection and negotiate an exclusive license prior to publishing. In these cases, the options are similar to that of the firm. The partnership cost depends on whether the knowledge outcome is commercially relevant. If knowledge outcomes are commercially relevant, the probability that the firms will not wish to collaborate in the future increases. Thus, size of partnership cost depends on the expected value of future collaborations with the specific partner.Academics expectedly will choose to publish immediately when the value of the partnership is low, or the knowledge has no direct commercial value. However, when the partnership is valued highly. This could be in situations where the academics rely on the frim for funding, machinery or materials; they will likely select an accommodation strategy as soon as the knowledge has expected commercial value to the firm.

The conceptual model implies that when knowledge outcomes are purely relevant for commercial use, firms and academics will select a dissemination strategy that maximizes returns on investments, namely secrecy or similar. The exact method of protecting knowledge will depend on which party has the right to the knowledge. When outcomes are purely relevant for publishing, firms and academics alike will select a dissemination option that includes publication. However, when knowledge outcomes are both commercially relevant and publishable, the dissemination strategy depends on which collaborator has the contractual right to knowledge, the difference in expected utility between the collaborators preferred option and the option, which accommodates the partner, the evaluation of the partnership, the risk that the preferred option will harm said partnership.

	Commercially relevant	Not commercially relevant
Scientifically relevant	Dependent on contractual ownership, initial objective, partnership characteristics, cost-benefit structures of disclosure/non-disclosure versus alternative solutions satisfying both disclosure and appropriation	Published by means best serving the academics
Not scientifically relevant	Protected by means best serving the firm	

While this model simplifies the decision-making of the partners in a university-industry project, it provides a model from which to discuss central issues of knowledge production in the context of university-industry projects. The model resembles the typology in M. Perkmann and Walsh (2009) which argues that the objectives of a project relate to the degree to which projects lead to publication. Their model predicts when projects likely lead to secrecy issues, however it does not provide a way to understand how "secrecy issues" are resolved. What this model provides in extension to that of Perkmann and Walsh, is a way to discuss and understand how the potential conflicts are resolved. In this model, I suggest that the key to understanding whether protection or publication is chosen is through the contractual division of rights and the perceived value of the partnership by the controlling party.

There are limitations to this conceptual model. This model takes its starting point at the end of a project, where knowledge is "known" and parties are able to evaluate the potential value of said knowledge. However, there are a number of factors relevant for the decision to publish that occur prior to this stage. Moreover, partners are aware of each others' preferences, which may affect the way the contract is formulated and how the partners work with each other during the project. Finally, projects do not simply lead to one solitary piece of knowledge that can be either published or kept secret. Nor can knowledge in practice be classified in a simple classification based on commercial and scientific relevance. Moreover, often knowledge is entangled with other assets, tacit skills and knowledge which makes it ever more complex. Finally, the model does not directly include the fact that academics may benefit from and prefer to engage in commercialization at the expense of publication. However, I argue that this conceptual model can be used as a starting point where such complexities can be added and the potential consequences discussed.

A set of implications for understanding knowledge production and dissemination in UIPs can be derived from the conceptual model. First, the conceptual model suggests that when academics are highly dependent on a few corporate sponsors for research, publishing is likely often postponed, altered or foregone in university-industry projects. Second, when firms are highly dependent on a research group for continuous knowledge and asset flow, publishing is more likely. Third, the contractual division of IPR can guide the dissemination strategy, yet does necessarily lead to the expected outcome. Thus, enforcing a strict publication clauses that allows academics to publish, may not mean that academics actually will publish if they expect is will harm their future relationship with an important partner. Finally, while it is often highlighted how firms engage with academics in order to build absorptive capacity and connectedness, through the model I argue that this does in itself not imply that firms will engage in publishing. However, it is likely the firms follow an open innovation strategy may place a higher value on partnerships with academics and thereby be more likely to accommodate academics in terms of publishing.

References

Bayona, C., Garcia-Marco, T., & Huerta, E. (2001). Firms' motivations for cooperative R&D: an empirical analysis of Spanish firms. *Research Policy, 30*(8), 1289-1307. doi:10.1016/s0048-7333(00)00151-7

Behrens, T. R., & Gray, D. O. (2001). Unintended consequences of cooperative research: impact of industry sponsorship on climate for academic freedom and other graduate student outcome. *Research Policy, 30*(2), 179-199. doi:10.1016/s0048-7333(99)00112-2

Bekendtgørelse af lov om opfindelser ved offentlige forskningsinstitutioner, 210, Ministeriet for Videnskab, Teknologi og Udvikling (1999).

Bercovitz, J. E. L., & Tyler, B. B. (2014). Who I Am and How I Contract: The Effect of Contractors' Roles on the Evolution of Contract Structure in University-Industry Research Agreements. *Organization Science, 25*(6), 1840-1859. doi:10.1287/orsc.2014.0917

Blumenthal, D., Campbell, E. G., Causino, N., & Louis, K. S. (1996). Participation of life-science faculty in research relationships with industry. *New England Journal of Medicine, 335*(23), 1734-1739. doi:10.1056/nejm199612053352305

Bozeman, B., Fay, D., & Slade, C. P. (2013). Research collaboration in universities and academic entrepreneurship: the-state-of-the-art. *Journal of Technology Transfer, 38*(1), 1-67. doi:10.1007/s10961-012-9281-8

Cockburn, I. M., & Henderson, R. M. (1998). Absorptive Capacity, Coauthoring Behavior, and the Organization of Research in Drug Discovery. *The Journal of Industrial Economics, 46*(2), 157-182. doi:10.1111/1467-6451.00067

Cohen, W. M., & Levinthal, D. A. (1989). INNOVATION AND LEARNING - THE 2 FACES OF R-AND-D. *Economic Journal, 99*(397), 569-596. doi:10.2307/2233763

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2002). Links and Impacts: The Influence of Public Research on Industrial R&D. *Management Science, 48*(1), 1-23. doi:10.1287/mnsc.48.1.1.14273

Crespo, M., & Dridi, H. (2007). Intensification of university-industry relationships and its impact on academic research. *Higher Education, 54*(1), 61-84. doi:10.1007/s10734-006-9046-0

D'Este, P., & Perkmann, M. (2011). Why do academics engage with industry? The entrepreneurial university and individual motivations. *Journal of Technology Transfer, 36*(3), 316-339. doi:10.1007/s10961-010-9153-z

Dasgupta, P., & David, P. A. (1994). TOWARD A NEW ECONOMICS OF SCIENCE. *Research Policy, 23*(5), 487-521.

Dutrenit, G., De Fuentes, C., & Torres, A. (2010). Channels of interaction between public research organisations and industry and their benefits: evidence from Mexico. *Science and Public Policy, 37*(7), 513-526. doi:10.3152/030234210x512025

Eisenberg, R. S. (1987). Proprietary rights and the norms of science in biotechnology research. *Yale LJ, 97*, 177.

Franzoni, C., Scellato, G., & Stephan, P. (2011). Changing Incentives to Publish. *Science, 333*(6043), 702-703. doi:10.1126/science.1197286

Garcia, R., Araújo, V., Mascarini, S., Santos, E. G., & Costa, A. R. (2020). How long-term university-industry collaboration shapes the academic productivity of research groups. *Innovation, 22*(1), 56-70. doi:10.1080/14479338.2019.1632711

Geuna, A. (2001). The changing rationale for European university research funding: Are there negative unintended consequences? *Journal of Economic Issues, 35*(3), 607-632.

Harhoff, D., Henkel, J., & von Hippel, E. (2003). Profiting from voluntary information spillovers: how users benefit by freely revealing their innovations. *Research Policy, 32*(10), 1753-1769. doi:https://doi.org/10.1016/S0048-7333(03)00061-1

HICKS, D. (1995). Published Papers, Tacit Competencies and Corporate Management of the Public/Private Character of Knowledge. *Industrial and Corporate Change, 4*(2), 401-424. doi:10.1093/icc/4.2.401

Landry, R., Traore, N., & Godin, B. (1996). An econometric analysis of the effect of collaboration on academic research productivity. *Higher Education, 32*(3), 283-301. doi:10.1007/bf00138868

Larsen, M. T. (2011). The implications of academic enterprise for public science: An overview of the empirical evidence. *Research Policy, 40*(1), 6-19. doi:10.1016/j.respol.2010.09.013

Laursen, K., & Salter, A. J. (2014). The paradox of openness: Appropriability, external search and collaboration. *Research Policy, 43*(5), 867-878. doi:10.1016/j.respol.2013.10.004

Li, Y., Youtie, J., & Shapira, P. (2015). Why do technology firms publish scientific papers? The strategic use of science by small and midsize enterprises in nanotechnology. *The Journal of Technology Transfer, 40*(6), 1016-1033. doi:10.1007/s10961-014-9391-6

Mansfield, E. (1998). Academic research and industrial innovation: An update of empirical findings. *Research Policy, 26*(7-8), 773-776.

McCabe, A., Parker, R., & Cox, S. (2016). The ceiling to coproduction in university–industry research collaboration. *Higher Education Research & Development, 35*(3), 560-574. doi:10.1080/07294360.2015.1107888

Merton, R. K. (1957). PRIORITIES IN SCIENTIFIC DISCOVERY - A CHAPTER IN THE SOCIOLOGY OF SCIENCE. *American Sociological Review, 22*(6), 635-659. doi:10.2307/2089193

Merton, R. K. (1969). BEHAVIOR PATTERNS OF SCIENTISTS. *American Scientist, 57*(1), 1-&.

Mitroff, I. I. (1974). Norms and Counter-Norms in a Select Group of the Apollo Moon Scientists: A Case Study of the Ambivalence of Scientists. *American Sociological Review, 39*(4), 579-595. doi:10.2307/2094423

Mowery, D. C., & Sampat, B. N. (2004). The Bayh-Dole Act of 1980 and university-industry technology transfer: A model for other OECD governments? *Journal of Technology Transfer, 30*(1-2), 115-127. doi:10.1007/s10961-004-4361-z

Perkmann, M., Salandra, R., Tartari, V., McKelvey, M., & Hughes, A. (2021). Academic engagement: A review of the literature 2011-2019. *Research Policy, 50*(1), 104114. doi:https://doi.org/10.1016/j.respol.2020.104114

Perkmann, M., & Walsh, K. (2009). The two faces of collaboration: impacts of university-industry relations on public research. *Industrial and Corporate Change, 18*(6), 1033-1065. doi:10.1093/icc/dtp015

Robinson, W. T., Kalyanaram, G., & Urban, G. L. (1994). First-mover advantages from pioneering new markets: A survey of empirical evidence. *Review of Industrial Organization, 9*(1), 1-23. doi:10.1007/BF01024216

Rockett, K. (2010). Chapter 7 - Property Rights and Invention. In H. H. Bronwyn & R. Nathan (Eds.), *Handbook of the Economics of Innovation* (Vol. Volume 1, pp. 315-380): North-Holland.

Rosenberg, N. (1990). WHY DO FIRMS DO BASIC RESEARCH WITH THEIR OWN MONEY. *Research Policy, 19*(2), 165-174. doi:10.1016/0048-7333(90)90046-9

Salter, A. J., & Martin, B. R. (2001). The economic benefits of publicly funded basic research: a critical review. *Research Policy, 30*(3), 509-532. doi:10.1016/s0048-7333(00)00091-3

Slaughter, S., & Leslie, L. L. (2001). Expanding and Elaborating the Concept of Academic Capitalism. *Organization, 8*(2), 154-161. doi:10.1177/1350508401082003

Stephan, P. E. (1996). The economics of science. *Journal of Economic Literature, 34*(3), 1199-1235.
Stephan, P. E. (2004). Robert K. Merton's perspective on priority and the provision of the public good knowledge. *Scientometrics, 60*(1), 81-87. doi:10.1023/b:scie.0000027311.17226.70
Stephan, P. E., & Levin, S. G. (2001). Career stage, benchmarking and collective research. *International Journal of Technology Management, 22*(7-8), 676-687. doi:10.1504/ijtm.2001.002985
Stokes. (1997). Pasteur's_Quadrant.
Styrelsen for Forskning og Innovation, A. o. E. (2015). *Kommercialisering of forskningsresultater 2014 og kortlægning af videnssamspil i bredere perspektiv*. Retrieved from Copenhagen K: https://ufm.dk/publikationer/2015/kommercialisering-af-forskningsresultater-2014
Teece, D. J. (2010). Chapter 16 - Technological Innovation and the Theory of the Firm: The Role of Enterprise-Level Knowledge, Complementarities, and (Dynamic) Capabilities. In H. H. Bronwyn & R. Nathan (Eds.), *Handbook of the Economics of Innovation* (Vol. Volume 1, pp. 679-730): North-Holland.
Ziman, J. (2000). *Real Science: What it Is and What it Means*. Cambridge: Cambridge University Press.
Ziman, J. M. (1994). *Prometheus bound*: Cambridge University Press.
Aagaard, K. M., Niels; Degn, Lise; Sorensen, Mads P; Bloch, Carter; Ravn, Tine; Hansen, Hanne Foss. (2012). *Dansk forskningspolitik efter årtusindskiftet* (K. M. Aagaard, Niels Ed.). Gylling, Denmark: Aarhus Universitetsforlag.

Chapter 5: Public dissemination of scientific knowledge in university-industry projects

Abstract

Numerous studies have discussed and analysed how interaction with industry affects academic productivity. Few however, have studied whether different types of projects may lead to different levels of published research. Based on a qualitative study Perkmann and Walsh (2009) argue that the dissemination of scientific knowledge produced in university-industry projects relates to the finalization of project objectives.

This study investigates a sample of 117 university-industry projects in an attempt to conceptually replicate and quantify the central proposition of the study. Based on regression analyses, the study finds that there is a weak negative relationship between finalization and the dissemination of knowledge in university-industry projects that is mainly driven by a relatively low tendency for problem solving projects to lead to project related publications. Additionally, the study finds that, given the degree of finalization, partner firms´ financial and practical involvement in projects negatively relates to the occurrence, amount and timing of project-related publications.

The results suggests that academic project participants are able to co-design and opt into projects that, irrespective of the projects´ primary objective, have the potential to generate new academic knowledge relevant to their academic peers. The public dissemination of project-related findings however, is marginally hampered or deselected when projects are highly finalized or when firms are highly involved in projects.

Introduction

The exchange and co-creation of knowledge between researchers and private market actors has become an increasingly important activity in academia. Collaborative projects that involve industrial partners as collaborators, contractors and funders are widespread in many academic disciplines.Moreover, increased interaction between academia and industry is promoted politically, and has become a central strategy for universities and firms alike.

University-industry collaboration can provide academics access to knowledge, ideas and resources and facilitates links to industry for students and faculty (D'Este & Perkmann, 2011). Additionally, involving industry in research projects can increase the chances of obtaining funding in an otherwise competitive funding system (Stephan, 1996). Similarly, industry can benefit from collaboration by obtaining “windows to technology”, building innovation and absorptive capacity, and as a source of problem solving capacity (Cohen, Nelson, & Walsh, 2002; Laursen & Salter, 2004)

University-industry interaction may however also have unfavourable consequences from an academic lens. The interaction with industry can potentially cause conflicts about when, how, or whether or not to disseminate relevant scientific findings to the scientific community (Ziman, 2000). Dissemination of knowledge may be hampered by commercial interests that may conflict with the scientific norm of openness and lead to delays, editing or suppression of research results (Dasgupta & David, 1994). In addition, the knowledge produced and the methods used in university-industry collaborations may not be sufficiently relevant or scientific to share in academic journals. University-industry projects might be directed towards more application-oriented objectives and deviate from scientific methodologies (Florida, 1999; M. Perkmann & Walsh, 2009). Scholars have argued that academic engagement can provide complimentary benefits and improve academic research outcomes through access to knowledge, new ideas, capital and funding (D'Este & Perkmann, 2011; Markus Perkmann, Salandra, Tartari, McKelvey, & Hughes, 2021; M. Perkmann et al., 2013). Hence, the academic outcomes from university-industry collaboration may depend both on the objectives and design of the collaboration itself and on the nature of the research involved in the project.

Studies of the relationship between university-industry collaboration and academic productivity have generally not taken into account the role of different project characteristics. Instead, they tend to focus how engagement in consultancy, joint research or receipt of industry funding affects the productivity of the engaged scholar (Blumenthal, Campbell, Causino, & Louis, 1996; Gulbrandsen & Smeby, 2005; Lin & Bozeman, 2006). University-industry projects can take many forms, ranging from scientifically motivated joint research to consultancy work, with potentially large implications for what types of outputs come out of these projects. Despite the fact that university-industry interaction is a key goal of research and innovation policy, little work has been done to understand the relation between project characteristics and the related research outcomes.

An important exception is Perkmann and Walsh 2009, who argue, that academic publishing in the context of university-industry projects depends on the shared project goals.According to Perkmann and Walsh, projects with a high degree of finalization (projects with commercial and market-oriented objectives) are less likely to lead to academic publications than projects with a low level of finalization.

The results and findings presented in the study by Perkmann and Walsh have been frequently cited in scholarly literature; however, the central propositions have not yet been examined in a different context. In this article, I investigate to what extent dissemination of scientific findings through publication in peer-reviewed journals is associated with the type of the university-industry project. In particular, I analyse and revisit the hypothesized relationship between the degree of finalization of a university-industry project and the propensity to publish project-related knowledge (M. Perkmann & Walsh, 2009). Additionally, I explore whether the degree to which firms participate and contribute to university-industry projects can predict variation in the occurrence, timing and number of project-related publications.

Drawing on Perkmann and Walsh (2009), I categorize a sample of 117 university-industry projects into four types according to their level of finalization based on objectives and tasks described in project descriptions: Problem solving (high degree of finalization), Technology development (medium to high degree of finalization), Ideas testing (low to medium degree of finalization) and Knowledge generation (low degree of finalization).

I match projects to project-related publications using information on academic participants, industrial partners, project descriptions, and funding information. Finally, I include variables of project size and degree of industrial partner involvement. In three separate regression analyses, I analyse the relationship between project finalization and three measures of project-related publishing: a binary variable measuring whether or not a project leads to publication, total number of project-related publications and the time between project initiation and the publication of the first project-related publication.

This study provides a fine-grained systematic quantitative analysis of the proposed relationship between finalization and publication outcomes. Moreover, the study focuses on the project as the unit of analysis, whereas the majority of studies within this area treat the individual academic as the unit of analysis. The findings thus provide a different lens to look through when discussing the academic consequences of university-industry interaction. Finally, this project level analysis allows a direct coupling between academic engagement and academic production.

The analyses indicate that project finalization correlates negatively to the likelihood amount and timing of project-related publications. However, the quantitative differences are most notable between problem-solving projects (high degree of finalization) compared to the remaining three types of projects. While, the differences in publication behaviour between projects with low to moderate levels of finalization are only marginal. These projects lead to project-related publications in the majority of cases.Additionally, I find that the degree of industry partner contribution to and involvement in projects relates negatively to the propensity, amount and timing of project-related publications.

The findings of the study suggest that for the most part academics engaged in university-industry projects are able to pursue and publish relevant research in their field. Project-related publication is however, marginally hampered or deselected when projects´ objectives are highly finalized and when collaborating firms have a high degree of financial or practical involvement in projects.

Literature review

Scholars have defined and categorized the interaction between public research and private enterprise in numerous ways. The literature contains a variety of concepts such as university-industry- or public-private- linkages, links, interactions, relationships, cooperation, knowledge transfer, technology transfer, interaction channels, or collaboration. A number of empirical and theoretical typologies and intuition-based categorizations of university-industry interaction have been developed (Arza, 2010; D'Este & Perkmann, 2011; De Fuentes & Dutrenit, 2012; M. Perkmann & Walsh, 2007; Ramos-Vielba, Fernandez-Esquinas, & Espinosa-de-los-Monteros, 2010; Schartinger, Rammer, Fischer, & Frohlich, 2002). University-industry interactions often considered to be included in the various concepts are joint research, contract research, sponsored research, consulting, informal meetings, licensing of IPR, academic spin-outs, researcher mobility, graduate training and industrial use of academic literature (Cohen et al., 2002; Schartinger et al., 2002).

The core focus of this study is the knowledge dissemination practices in relation to university-industry projects. Specifically, university-industry projects refers to university-industry collaborations delimited by an overall objective, deliverables, sets of task, timeframe and budgets. University-industry collaboration refers to the transfer, exchange or co-creation of knowledge or technology between researchers and private market actors.

Perkmannn and Walsh (2007) provide a thorough overview of university-industry links, dividing them into seven categories: Research partnerships, Research Services, Academic entrepreneurship, Human resource transfer, Informal interaction, Commercialization of property rights, and scientific publications. University-industry projects thus include what Perkmann and Walsh (2007) call research partnerships and research services (i.e. consultancy, contract research, sponsored research and collaborative research.)

When academics participate in university-industry projects, it is often referred to as academic engagement (M. Perkmann et al., 2013). Academic engagement however also refers to indirect and informal interactions with industry. A related concept, academic entrepreneurship, refers to commercialization activities researchers engage in including patenting, licencing inventions and creating spinouts.

Studies have found that academic engagement is relatively frequent and widespread in the scientific community and much more so than academic entrepreneurship (M. Perkmann et al., 2013). In D’este and Perkmann (2011) 44, 47 and 38 % of the surveyed researchers within Physical & engineering sciences in the UK reported to be engaged in collaborative research, contract research and consultancy respectively over a two-year period (D'Este & Perkmann, 2011). In a survey of academics in Sweden, Klofsten and Jones-Evens (2000) find that over an entire career 50 % of the researchers reported to have been engaged in consultancy, 44% in sponsored research and 45 % on contracted research.

Multiple studies have attempted to estimate the effect of academic engagement on academics’ research productivity (Blumenthal et al., 1996; Goldfarb, 2008; Gulbrandsen & Smeby, 2005; Lin & Bozeman, 2006). The studies generally find that academics who engage with industry are slightly more productive than their non-engaging peers, though a recent study found a negative effect on research productivity from engaging in consultancy (Rentocchini, D'Este, Manjarrés-Henríquez, & Grimaldi, 2014). In additional, there are also indications that sustained engagement or too high a proportion of funding from industry has a negative marginal effect on research output (Markus Perkmann et al., 2021; M. Perkmann et al., 2013). Moreover, studies suggest that interaction with industry can affect the degree of secrecy practiced by academics (Lin & Bozeman, 2006).

Most empirical studies on the topic analyse the relationship between the aggregate number of academic outputs and academic engagement by comparing the academic production of engaged academics with non-engaged academics in a period after interaction. Thus, they do not identify the direct outcomes from the interaction. Furthermore, the studies do not examine whether knowledge dissemination behaviour differs depending on the specific type and context of engagement. Therefore, analysing publication behaviour at the level of projects provides a much needed level of granularity (Nunez-Sanchez, Barge-Gil, & Modrego-Rico, 2012; M. Perkmann et al., 2013). Project-level analysis provides the opportunity to link university-industry projects directly to project-related outcomes while accounting for the type and characteristics of the project. On the other hand, project level analysis does not lend itself well to the question of whether academic productivity of individual academics is affected by engagement compared to non-engagement.

A number of studies have analysed university-industry interactions at the project level, but do not focus on project-related publication outcomes (Caloghirou, Tsakanikas, & Vonortas, 2001; Levy, Roux, & Wolff, 2009; Morandi, 2013; Ramos-Vielba et al., 2010). Only three studies, to my knowledge, directly examine the relationship between knowledge dissemination practices and project-specific characteristics. Two studies examine the relationship between participant-specific project characteristics and publication outcomes and impact in a sample projects funded by a specific funding instrument in Spain (Banal-Estanol, Macho-Stadler, & Perez-Castrillo, 2013; Nunez-Sanchez et al., 2012).

Drawing on survey-based data coupled with basic project information, (Nunez-Sanchez et al., 2012) study 196 projects funded by PETRI between 1989-1995. They find that the size of the project, the proportion of tasks paid for or performed by the firm and the previous collaborative experience between the partners are positively related to the number of international peer-reviewed articles. Banal-Estañol (2013) find that collaborative projects are likely to lead to more publications than non-collaborative projects when the number of past publications by the firm are sufficiently high.

The benefit of the two cited studies is that they are able to hold the overall type of project constant and thereby study the effects of detailed partnership characteristics on project outcomes. The benefit of the study by Perkmann and Walsh is the ability to distinguish between different project types and contexts.

Based on 43 interviews at an engineering faculty at a UK university with researchers with high levels of industry involvement, Perkmann and Walsh (2009) examine publication behaviour in projects with different objectives.They identify 55 instances of university-industry projects and produce narrative summaries of each project, and inductively derived a four-fold typology of collaborative projects that differ in terms of their degree of finalization. Finalization is defined as “the degree to which scientific research pursues a specific purpose as opposed to gaining new knowledge for the sake of itself” (M. Perkmann & Walsh, 2007). In Perkmann and Walsh (2009) they argue that the shared project objectives between academics and industrial partners can be placed on this finalization continuum.

In descending order of finalization, Perkmann and Walsh (2009) identify four project types: problem solving, technology development, ideas testing, and knowledge generation. Table 1 summarises the four types. Projects that aim to solve technical problems and challenges for a firm have a high degree of finalization, while research projects aiming to understand a phenomenon or an empirical relationship have a low degree of finalization. Projects that aim to investigate the feasibility of potentially commercially interesting ideas and projects that aim to develop new or improve existing technologies of commercial interest to the industrial partners have an intermediate level of finalization. Projects with a low degree of finalization are conducive to academic publishing because the content is similar to traditional research projects and thus relevant to scientific community. Additionally, the outputs of the projects are not immediately commercially valuable and therefore publishing does not affect the commercial opportunities of the sponsoring firm. Projects with a high degree of finalization are more likely to exhibit secrecy issues that limit academic publication: Academics may opt to postpone publishing for appropriation reasons and firms may demand secrecy to protect commercial opportunities. Furthermore, projects with a high degree of finalization tend to suffer from relevance issues: Projects are not academically interesting or because of the time-pressure and project context, the methods are not sufficiently rigorous for scientific publication. Finally, projects with intermediate levels of finalization can exhibit issues of secrecy as well as relevance.

Table 1: Perkmann and Walsh model (edited by author)

Project type	Knowledge generation	Ideas testing	Technology development	Problem solving
Project description (Perkmann and Walsh 2011)	Carrying out research on topics of broad interest to a firm	Exploring a high-risk concept on behalf of a firm – outside the firm's mainstream activities	Developing design specifications or prototypes for new or improved products or processes	Providing advice regarding technical problems arising within a firm's R&D, manufacturing or other operations
Degree of finalization	Low degree of finalization	Low to medium	Medium to high	High degree of finalization
Impact on academic publishing	Conducive to publishing	Secrecy problems		Relevance Problems

Created by author based on Perkmann and Walsh (2009).

The results and findings presented in the study by Perkmann and Walsh have been highly cited in scholarly literature[1]. However, the central propositions have not yet been examined in a different context. Additionally, the extent to

[1] In Web of Science the publication has received 166 citations since 2009 (Date of data extraction 04-10-2020).

which finalization and publication behaviour are related cannot be derived from their qualitative work.While Perkmann and Walsh solve the issue of directionality by linking publication behaviour directly to university-industry projects, and provide a leap in understanding of how different projects may relate to knowledge production and subsequent dissemination, the approach does not quantify or establish whether the argued relationship is generalizable or replicable outside their study. I argue that there is a need to investigate the hypothesized relationship between finalization and dissemination of research output at the project level quantitatively in a larger setting in a more formal and quantitative set-up.

In this article, I revisit the central propositions provided by Perkmann and Walsh using contract-based data at the project level enriched with bibliometric information on project-related outcomes.

The central proposition put forth by Perkmann and Walsh is that the degree of finalization of a project is negatively related to the publication of project-related outcomes. I investigate both whether the relationship between finalization and publication can be observed and the extent to which the propensity to publish and quantity of publications correlates with differing degrees of finalization. The first proposition can be stated as:

i. The degree of finalization in a university-industry project relates to a) publishing and b) the quantity of project related publications.

Perkmann and Walsh propose that the degree of finalization of a project is negatively related to the publication of project related findings through two mechanisms: secrecy and relevance. They provide examples of how secrecy issues lead to postponement of publications in projects with a medium to high degree of finalization. As an extension of this proposition, one would expect that the finalization of projects correlate positively with the duration between project initiation and first publication. The proposition can be stated as:

ii. The degree of project finalization relates tothe time between project initiation to publication of project-related results

In addition to the above-mentioned research questions, I ask whether other factors may relate to the propensity to publish project related findings that are not included directly in Perkmann and Walsh. Studies looking at specific types of projects have found that the proportional contribution of partner firms relates to the amount of published research (Nunez-Sanchez et al., 2012). The degree of industrial involvement in a project may indicate the commercial relevance to the firm, that the firm wishes to maintain control with the process and outcomes of projects and the degree of leverage the firm has in cases where knowledge outcomes are deemed sensitive. Therefore, I examine the following proposition:

iii. The degree of firm participation and contribution relates to the degree to which projects lead to project-related publications

Data and method

This study addresses the three research propositions above through three regression analyses that examine the relationship between 1) the incidence of publication, 2) the volume of publication and 3) the time from project start to first publication and project finalization as well as degree of firm contribution and participation.The dataset consists of a qualitatively derived measure of project finalization; project-level variables derived from budgets, contracts and project descriptions; and matched bibliometric data on project-related publications.

Data

The data consists of 117 university-industry projects performed by academic employed at the faculty of Science and technology, Aarhus University. The faculty of Science and Technology, Aarhus University consists of 13 departments.It is the largest faculty in the university that also consists of a Faculty of Arts, Faculty of Business and Social Sciences, and Faculty of Health. In 2017, the Faculty of Science and technology employed 1649 academic staff (FTE). The research areas represented in the projects include Engineering, Biology, Chemistry, Nanoscience, Computer Science, Geology, Molecular Biology, Animal Science, Food Science, Environmental Science, Physics and Astronomy.

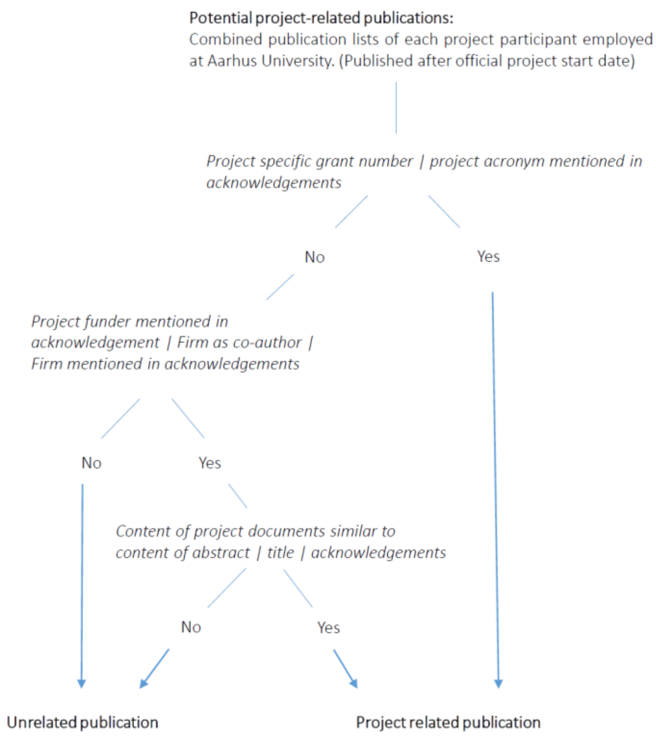
Inteum, is a management tool for the legal team in the technology transfer office at Aarhus University. From the Inteum database, I selected all projects (collaboration agreements, EU Agreements and sponsored research agreements) with participation of academics affiliated to the faculty of Science and Technology, Aarhus University that involve at least one firm, initiated between 2010 and 2014 and where projects where set to finish before 2018. I excluded projects where a project description, contract and/or budget was not available. Finally, I did not consider projects that involved more than 13 organizations. This was mainly due to the extreme difficulty in handling the complexity in coding when projects grew in the number of participants. Out of the 219 projects with industry participation initiated between 2010 and 2014, ended prior to December 2017 and had less than 14 organizations, 117 university-industry met the stated criteria.

For each project, I coded the names and addresses of firms and research organisations, as well as name, department, e-mail and academic position of Aarhus University academics. I coded funding and budget data with details of task performance and division of project funding. Finally, I qualitatively coded text into thematic codes, including project objectives, firm and university tasks and planned outputs.

Measuring project-related publications

Linking projects to publications that are directly related poses a number of challenges. Project participants, especially academics, continuously publish in international peer-reviewed journals from a myriad of different projects. Simply identifying all publications published by project participants in a period after a project has been initiated would include an extreme amount of false positives. I therefore, devised a method that could identify publications that are highly likely to be outcomes from a specific project. In total, 418 project-related publications for 117 projects were identified. The method is illustrated in a decision tree in figure 1.

Figure 1: Identification and selection strategy for project-related publications



As a first step, I compiled a list of publications for each academic involved in the project using the author disambiguation algorithm in the CWTS enhanced version of the Web of Science database (Caron, E. & van Eck, N.J. 2014).

Names and e-mails of academic project participants employed at Aarhus University were used to identify publication lists. For practical purposes, publication lists were based only on researchers from Aarhus University. This means that any project-related publications that do not include at least one co-author from Aarhus University are not included.

Second, for each project, I batch search the list of potential project-related publications in the web-based version of Web of Science and select publications that satisfy a set of inclusion criteria. Each publication positively identified as a project related publication is recorded with identification number and the inclusion criteria that applies to the publication.

Publications are considered directly linked to the project in question when,

1. The authors acknowledge the project by name, acronym and/ or grant number in the acknowledgements of the publication. 322 of 418 project-related publications where identified through this criterion. The majority of projects are funded by private and public funding organizations and thereby have an assigned project id, title and acronym.
2. The funder of the project or the partnering firm is mentioned in the acknowledgements or the partnering firm is a co-author *and* the content of the abstract, acknowledgements and title are similar to the content of the project description or in other ways points to a direct link between the project and publication. (96 of 418 publication where identified through this criterion.) In some cases, authors may shorthand acknowledgements without mentioning any specific project but only the funding agency or private funder. In these cases, publications may be related to a project funded by the same funder but in a different project initiated earlier, simultaneously or later. In order to ensure that these publications are not included as project-related publications I manually compare the abstract of the publication with the project description and disqualify publications that thematically are different from the project description.

Four variables are constructed based on the project related publications. *Publish* is a binary variable that takes the value 1 if at least one project-related publication is identified. *Publications* is a continuous variable measuring the number of project related publications. *Publication duration* is the duration in days between the start date of a project and the publication date of the first project-related publication. *Publication window* is a continuous variable that measures the duration in days from project start date and the data collection date. Since the start date of projects differ and the data collection date is the same, projects have different windows to publish. Shorter windows may mean that fewer publications are observed, while longer windows provides time for academics to write, submit and publish publications.

Measuring finalization

I categorize projects in terms of their degree of finalization using the four ideal types described in Perkmann and Walsh (2009). I operationalize the four types into mutually exclusive categories in order to be able to code each project consistently. Since Perkmann and Walsh do not provide definitions that can be directly applied for coding this data, I define definitions and coding criteria for the four types based on descriptions, examples and discussions put forth in the article by Perkmann and Walsh. The definitions and coding criteria of each of the four types are presented in table 2. The definitions focus on two aspects: the object and the objective of the project. The object becomes less tangible the further from the market, and the objective goes from providing practical solutions to concrete problems to understanding phenomena or empirical relationships.

Projects are coded based on a qualitative judgement of text in relation to the typology definitions. As such, projects that are "in-between" two types only receive one typology coding. Only a handful of projects where in fact borderline cases. These where often between knowledge generation and ideas testing or between ideas testing and technology development.

For ideas testing, a borderline case may be when a project takes a clear scientific approach (hypothesis testing), while the objective is formulated as an attempt to explore the technological feasibility of an idea or concept. I code the projects by their objective not their methodology, therefore such a project is coded as an ideas testing project. The difference between a technology development and ideas testing project depends to a large extent on the technological stage that thereby steers the objective. A borderline case may include a project in which a concept is defined and the objective is to assess the viability and feasibility of the concept and thereafter to translate the concept into a prototype. In this case, the projects´ primary objective is to first establish feasibility of concept, if the project does find it feasible, only then, does it become a technology development project. Projects that have a documented feasible concept and aim to develop or improve the technology are defined as technology development projects.

Four binary variables indicating the project type are derived *KG* (knowledge generation), IT (Ideas testing), *TD* (Technology development) and *PS* (problem solving). Moreover, an ordinal variable "*finalization*" measuring the concept of finalization from low to high with values 1-4 (KG=1, TD=2, IT=3 & PS=4). Out of the 117 projects, 15 are problem solving, 37 technology development, 30 ideas testing and 35 knowledge generation projects.

Table 2: Project type definitions and coding criteria

Project type	Definition	Coding criteria
Problem solving	The project aims to provide advice or a solution to a limited and clearly specified problem related to a company's existing product, process, machinery, equipment or ongoing R&D activities.	The project revolves around (one or more) companies' existing products, processes or concepts that are on or close to the market or parts of the firms machinery and equipment. The project objectives and tasks focused on solving or providing advice for solving a problem/challenge for the firm or the researchers provide a clearly specified service for a firm
Technology development	The project aims to develop a new or improve an existing product, process, technology or concept relevant to the participating firm(s).	The project attempts to develop a new or significantly improve or alter a product, process, technology, or other parts of the firms operations.
Ideas testing	The project aims to explore the theoretical and technical feasibility of a potentially commercially interesting idea or ideas	The project focuses on exploring a potentially commercially interesting idea (s) that is not yet translated into a concrete concept, prototype or technology. This will often be in the form of feasibility studies or experimentation.
Knowledge generation	The project aims to examine a hypothesis, to understand a process, the characteristics of a phenomenon, or relationship within a field with only limited reference to and activity towards commercial application.	The project examines a hypothesis, process, characteristics of a phenomenon, or relationship within a field with only limited reference to commercial application.

Measuring firm participation and contribution

The degree to which a firm participates in and contributes to a project may indicate a firm's desire and opportunity to influence the process and outcomes of a project.Therefore, projects with a high degree of firm contribution may be more likely to lead to delayed or foregone publication. Furthermore, projects with a high degree of firm engagement may more often be technical, practical and problem oriented projects and may therefore more often lead to knowledge outcomes that are not relevant to the scientific community. On the other hand, a study of projects found a marginal positive relationship between publishing and firm involvement (Nunez-Sanchez et al., 2012).

The proportion of the project budget that is either funded directly by the firm (in-cash) or performed by the firm (in-kind) measures firm participation. Consultancy projects or sponsored research projects will typically have a value of one because the entire budget is funded by the firm. While collaborative or co-funded projects can range between above zero to below 1.

Firm contribution theoretically relates to the degree of finalization. For example, when projects have practical objectives of relevance to the firm, they are often funded by the firm. A correlational analysis however, shows that they are in this empirical setting only moderately correlated, indicating that they are not substitutes or proxies for one another.

Description of projects

Below, the 117 projects are described in terms of size (duration and budget), participants (total number of organizations, firms, and research organizations), division of labour (proportion of budgeted tasks performed by industrial partners, Aarhus university staff and other research organizations), degree of external and firm funding, and financial engagement (proportion of budget funded by participating firms) and total firm contribution.

Projects categorized as problem solving are short-term projects consisting of one academic and one industrial partner. The budget is relatively small compared to the other project types. All activities are performed by the academic partner and funded exclusively by the partner firm. Measured by budgeted tasks, this type of project is non-collaborative. However, while firms do not have budgeted activities, they do in some cases provide material samples, data or information to the academic partner. Projects are organized as consultancy or contracted research projects in which the main output is results, advice and solutions reported to the contracting firm.

Technology development projects are long-term project with a relatively large budget, the project tends to consist of multiple partners from industry and academia. The number of industrial partners is often higher than the number of academic partners. Projects are highly collaborative with partner firms performing an average of 39 % of the planned tasks. Projects are often partially funded by firms or funding agencies that mainly focus on funding technology development and demonstration activities.

Ideas testing projects are long-term projects with a relatively high budget; the projects tend to consist of multiple partners from industry and academia. Projects are moderately collaborative: partner firms perform an overage of 20 % of the planned tasks. Projects are funded by firms or funding agencies focused on either technology development and demonstration activities or strategic research. Most projects are partially funded by a funding agency or private foundation. A few projects are funded either entirely or partially by the partner firms.

Table 3. Summary data for projects

	Problem solving	Technology development	Ideas testing	Knowledge generation	All projects
Project size[a)]					
Budget (1000 DKK)	695.26	12904.61	13038.93	7537.39	9768.17
Duration (Months)	12.5	31.4	36.4	31.2	30.2
Participants					
Organisations	2	4.3	5.1	3.7	4.0
Firms	1	2.4	2.6	1.6	2.0
Research Organisations	1	1.9	2.3	2	1.9
Division of labour					
Firms tasks (proportion)	0	.39	.20	.14	.21
AU Tasks (Proportion)	1	.50	.59	.70	.65
Other res orgs Tasks (Proportion)	0	.11	.21	.17	.14
Funding					
Third party funding (Proportion to budget)	0	.47	.53	.46	.43
Firm funding (Proportion to budget) (in-kind and in cash)	.99	.38	.30	.36	.43
Firm participation & Contribution					
Cash contribution and budgeted tasks (proportion of budget)	.99	.54	.36	.39	.51

Note: See appendix x for additional statistical measures min, max and standard deviation.

Empirically, the four project types have a set of characteristics that distinguish them from each other. Below I describe how they empirically compare to each other based on the statistical figures as well as the qualitative empirical material.

Knowledge generation projects are mid to long-term projects with a moderate budget. The projects tend to consist of a single or a few firms and a single or multiple research organizations. Firms play a relatively minor role in the execution of tasks. Projects are mainly funded by funding agencies who focus on strategic, mission-oriented or fundamental research. Approximately two-thirds of knowledge generation projects are partially funded by a funding agency. The remaining third are funded either entirely or partially by the partner firms. Projects funded by a third party are often larger and longer than those (co-)funded by partner firms.

Results

In this section, I analyse to what extent project finalization relates to whether, to what extent and how quickly university-industry projects lead to project related publications. First, I present descriptive statistics of publication outcomes for the four project types that differ in terms of finalization. Second, I present regression analyses where I take into account relevant co-variates. Lastly, I present the analysis of how firm contribution and participation in projects relates to publication outcomes given the degree of project finalization.

The publication outcomes for each of the four project types appear in the table 4 below. Two-thirds of the 117 projects lead to at least one project-related publication in the observed period. Problem solving projects lead to at least one publication in a third of the projects and technology development in two-thirds of the projects. In the projects with the lowest degree of finalization, 80 and 75 % of projects respectively lead to at least one peer-reviewed publication indexed by WoS. The difference in the occurrence of at least one publication between technology development, ideas testing and knowledge development projects is within 15 percentage points.

Table 4: Publication outcomes, by project type

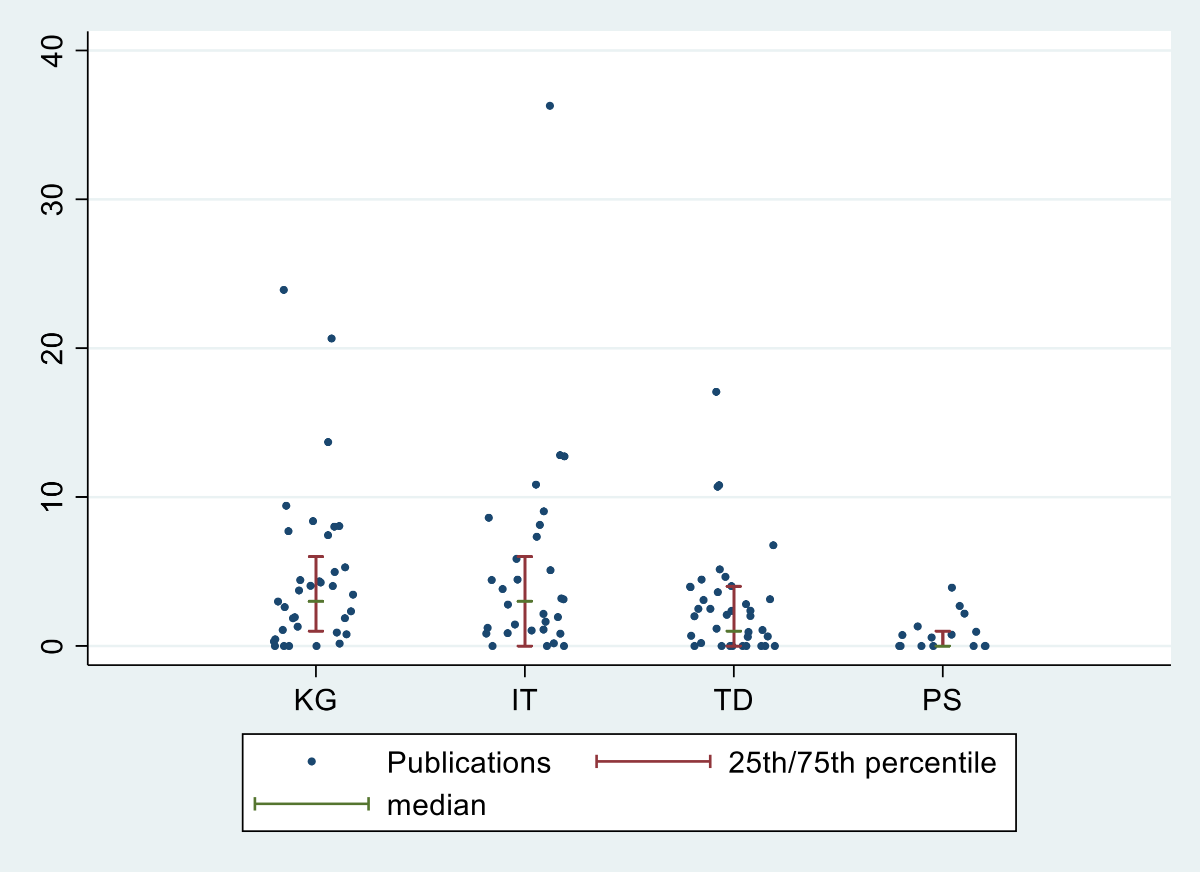
	Problem solving	Technology development	Ideas testing	Knowledge generation	All projects
Publish (1-0)	.33	.65	.80	.75	.68
Publications (mean) (Std dev)	0.47 (0.19)	2.5 (0.56)	4.7 (1.26)	4.3 (0.89)	3.4 (0.47)
Publications (median)	0	1	3	3	2
Publications per month[a)] (Std. dev)	0.008 (0.004)	0.037 (0.008)	0.066 (0.016)	0.061 (0.012)	0.048 (0.006)

Note: The sample of university-industry projects begin between 2010 and 2014. Project-related publications are counted in December 2018. Thus, the window for publishing project-related publications varies between projects. As a sensitivity analysis, I standardize the number of publications to the observation window. Row 3 in table 4 presents the average publications pr. month of observation for the four types of projects. The varied observation window does not affect the overall picture and the main differences between projects remain.

Overall, projects with a high degree of finalization lead to comparably fewer project-related publications than projects with a low to moderate level of finalization. On average, technology development projects lead to roughly half the amount of publications than the knowledge generation and ideas testing projects do. There is little difference between ideas testing and knowledge generation projects. In fact, the mean propensity and quantity of publications is slightly lower for knowledge generation projects than for ideas testing projects.

Figure 2 illustrates the distributions of total amount of project-related publications for each of the four types of projects. The median for all projects is two publications, yet there is a large group of projects that lead to more than five times the median. One ideas testing project is an extreme outlier with close to forty publications. The number of publications for problem solving projects and technology development projects is relatively more concentrated compared to ideas testing and knowledge development projects.

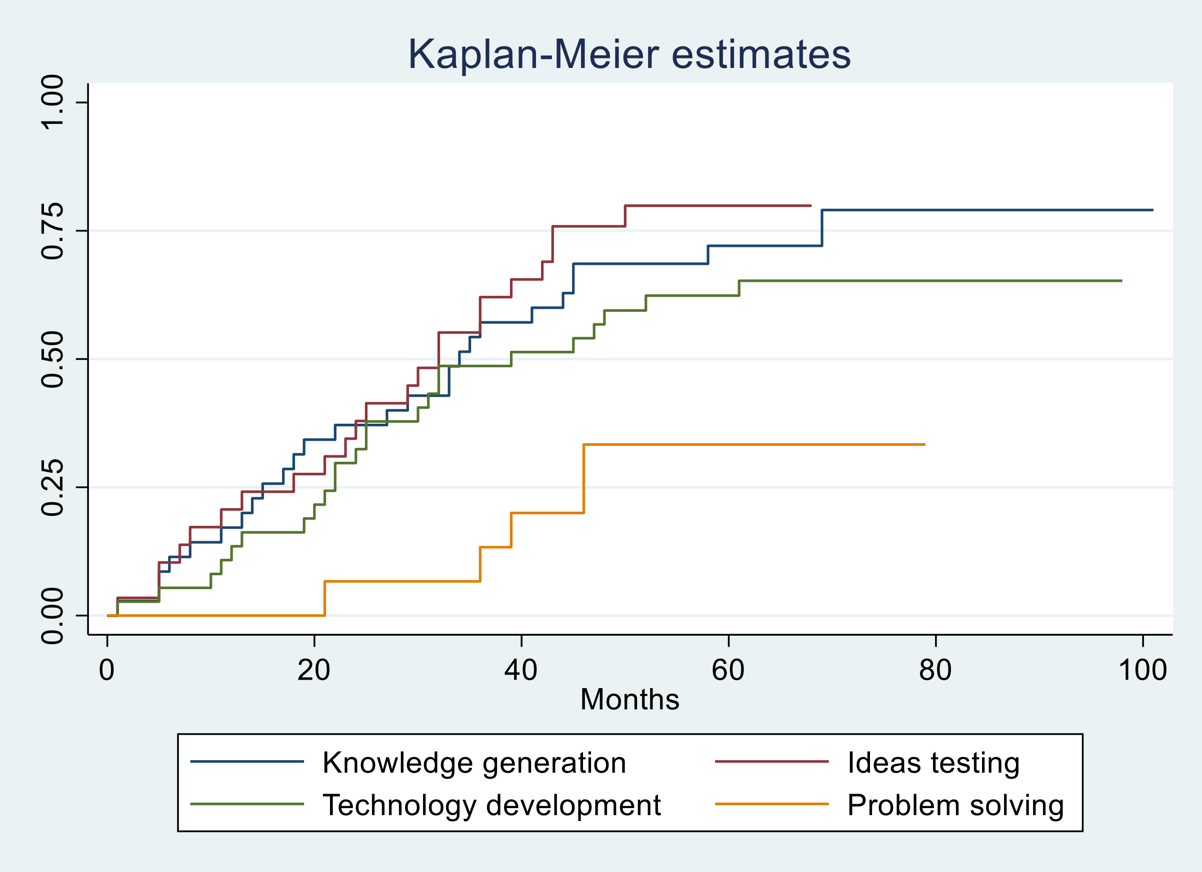
Figure 2: Project-related publications, by project type



Note: 75 % of observations are within red whiskers red lines indicate 25th and 75th percentile. Green line indicates median. Blue dots represent each observation within each project type.

The duration between from project start to first publication may reflect publication conflicts encountered in the project. Figure 3 shows the cumulative proportion of projects leading to publications on the y-axis and months after project initiation on the x-axis. The figure illustrates that in the short term very few projects with a high degree of finalization lead to publications, while a higher proportion of projects with a relatively low degree of finalization lead to a publication after only 20 months. The figure also shows that the gap narrows over time. After 50 months 68%, 73 % and 60 % of knowledge generation, ideas testing and technology development respectively lead to a publication. The basic descriptive analysis thus indicates that when projects have a high degree of finalization publication of project-related outputs is delayed compared to projects with a low to moderate degree of finalization. This can be interpreted as secrecy issues occurring more often in these types of projects and thus affecting publication behaviour.

Figure 3: Kaplan Meier failure estimates over finalization Failure=publication



Note: Cumulative proportion leading to publications on the y-axis and time on the x-axis. O.5 is the median time until publication – i.e. 50 % of projects lead to a publication within 34 months for KG, 32 Months for IT, 39 months for TD and cannot be calculated for PS as less than 50% lead to publications. Log rank test for differences between the four groups: Null hypothesis is equality between groups. The Chi2 value of 10.79 and 0.0129 indicates a rejection of the null-hypothesis that the hazard functions are equal across groups.It does not however, indicate that all hazard functions are significantly different from each other.

Results – Regression analyses

The descriptive analysis suggests that the degree of finalization, represented by the four project types, to some extent relates to whether projects lead to publications, the number of publications and when they are published. However, the differences especially between technology development, ideas testing and knowledge generation projects are only marginal. Average differences in publication outcomes may therefore relate to differences in other co-variates of finalization and publication. In the following section, I estimate the effect size of finalization on publication behaviour while adjusting for project size and publication window. Furthermore, I include a measure of firm participation in projects to examine whether firms' financial contribution and engagement relates to publication outcomes given the degree of project finalization.

Project finalization and the likelihood of project-related publication

I examine proposition 1.a (*The degree of finalization in a university-industry project relates to the propensity to publish*) through a logit regression model that estimates the relationship between project finalization and the likelihood that a university-industry project leads to at least one project-related publication. It includes budget size, proportional contribution of industrial partners and the period in which publication can be observed as controls.

The proportion of projects that lead to publications differs between the four project types. At a first glance, it seems that the probability that a project leads to a publication is to some degree related to the finalization of a project. Problem solving projects only lead to publications a third of the time, technology development two-thirds of the time while ideas testing and knowledge development projects lead to publications in 80 % and 75 % of the time.

Table 5 contains four logit regressions estimating the relationship between project finalization and the likelihood that a project leads to a publication taking into account relevant co-variates. Model 1 includes a dummy variable for each project type with problem solving as the base case. The observation window and budget size are included as controls. Model 2 includes observation window, budget and firm contribution. Contribution measures the proportion of the project budget that the participating firms fund in-kind or in cash. Model 3 includes all variables. Model 4 replaces the dummy variables of each of the four project types with an ordinal variable measuring finalization (1=knowledge generation, 2=ideas testing, 3=technology development, 4=problem solving).

The regression (model 1) shows that the propensity to publish is higher when projects have a low to moderate degree of finalization. Knowledge generation projects and ideas testing projects are 4.4 and 5.4 more likely to lead to publications than problem solving projects. Technology development projects are 2.4 more likely to lead to publications than problem solving (though statistically insignificant.) Additionally, t-tests for equality between the parameters for knowledge generation, ideas testing and technology development projects show that we cannot reject the hypothesis that they are equal. Thus, problem-solving projects are the only type of projects that have a statistically significant lower probability of leading to a publication. Furthermore, the estimated relationship finalization is lower and statistically insignificant when *contribution* is included as an independent variable (model 3 & Model 4).

Table 5: Propensity to publish - Logit regression

VARIABLES	(1) Model 1 logit	(2) Model 2 logit	(3) Model 3 logit	(4) Model 4 logit
Knowledge generation	1.521**		0.712	
	(0.700)		(0.788)	
Ideas testing	1.690**		0.892	
	(0.768)		(0.852)	
Technology development	0.888		0.293	
	(0.686)		(0.747)	
Publication window	0.00967	0.0155	0.0154	0.0150
	(0.0212)	(0.0195)	(0.0202)	(0.0204)
Budget	3.76e-05	2.43e-05	2.57e-05	2.68e-05
	(2.38e-05)	(2.20e-05)	(2.17e-05)	(2.21e-05)
Contribution		-2.052***	-1.612*	-1.699**
		(0.755)	(0.863)	(0.821)
Finalization				-0.249
				(0.229)
Constant	-1.367	0.611	-0.141	1.014
	(1.572)	(1.402)	(1.729)	(1.475)
Observations	117	117	117	117

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Project finalization and the amount of project-related publications

Proposition 1.b (*The degree of finalization in a university-industry project affects the quantity of project related publications*) is examined using a negative binomial regression model, which estimates the relationship between project finalization on the number of project-related publications given the budget size, proportional contribution of industrial partners and the period in which publications can be observed. The negative binomial model takes into account that there are a large number of projects that lead to zero publications, and the number of publications per project is skewed.

Table 6 contains negative binomial regression estimating the effect of finalization on number project related publications. The specifications of the four models are the same as for the estimation of the propensity to publish. The negative binomial regression indicates that there is a negative relationship between finalization and the amount of project related publications (Model 1 and model 4). When including a measure for firm contribution. The statistical significance of finalization depends on its operationalization (Model 3 – factor variables vs Model 4 – ordinal variable). T-tests for equality between the parameters (model 1) for knowledge generation, ideas testing and technology development projects show that we can reject the hypothesis that they are equal. In particular, the effect of being a knowledge generation project is significantly different from technology development and problem solving. However, we cannot infer that knowledge generation is different from ideas testing nor that technology development and ideas testing are different.

Table 6: Quantity of publications – Negative binomial regression

	(1)	(2)	(3)	(4)
VARIABLES	Model 1 NBR	Model 2 NBR	Model 3 NBR	Model 4 NBR
Knowledge generation	1.634***		0.895*	
	(0.471)		(0.512)	
Ideas testing	1.335***		0.657	
	(0.487)		(0.535)	
Technology development	0.948*		0.485	
	(0.485)		(0.528)	
Publication window	0.0231**	0.0275***	0.0260**	0.0260**
	(0.0104)	(0.0105)	(0.0105)	(0.0106)
Budget	4.78e-05***	3.50e-05***	3.78e-05***	3.83e-05***
	(8.35e-06)	(7.94e-06)	(7.84e-06)	(7.56e-06)
Contribution		-1.638***	-1.219***	-1.254***
		(0.344)	(0.372)	(0.351)
Finalization				-0.231**
				(0.101)
Constant	-2.319***	-0.546	-1.305	-0.169
	(0.879)	(0.744)	(0.990)	(0.754)
Observations	117	117	117	117

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Project finalization and the time to first project-related publication

Proposition 2 (The degree of finalization affect the time between project initiation to publication of project-related results) is examined using a Cox regression of the relationship between finalization and the time to first project-related publication. It includes budget size, proportional contribution of industrial partners and the period in which publication can be observed as controls.

In this section, I analyse the time to first publication as a hazard function. The aim is to estimate whether the event of publication is different for projects depending on their degree of finalization and firm contribution.

Table 7 contains a time to event analysis (cox regression) that estimates the effect of finalization and firm contribution on the duration from project initiation to publication of the first project-related publication. Model 1 includes a dummy variable for each project type with problem solving as the base case.Budget size is included as a control. Model 2 includes budget and the variable contribution. Model 3 includes all variables. Model 4 replaces the dummy variables of each of the four project types with an ordinal variable measuring finalization.

Table 7: Cox regression of publication hazard

	(1)	(2)	(3)	(4)
VARIABLES	Model 1	Model 2	Model 3	Model 4
Knowledge generation	1.134**	0.611		
	(0.496)	(0.567)		
Ideas testing	1.193**	0.701		
	(0.506)	(0.566)		
Technology development	0.705	0.403		
	(0.515)	(0.538)		
Contribution		-0.884**		-0.979**
		(0.422)		(0.414)
Budget	2.62e-05***	2.17e-05**	2.96e-05***	2.33e-05**
	(9.64e-06)	(1.01e-05)	(8.92e-06)	(9.73e-06)
Finalization			-0.300***	-0.137
			(0.113)	(0.136)
Observations	117	117	117	117

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Coefficients are interpreted as the predicted change in log hazard for a change of one unit of the co-variate.

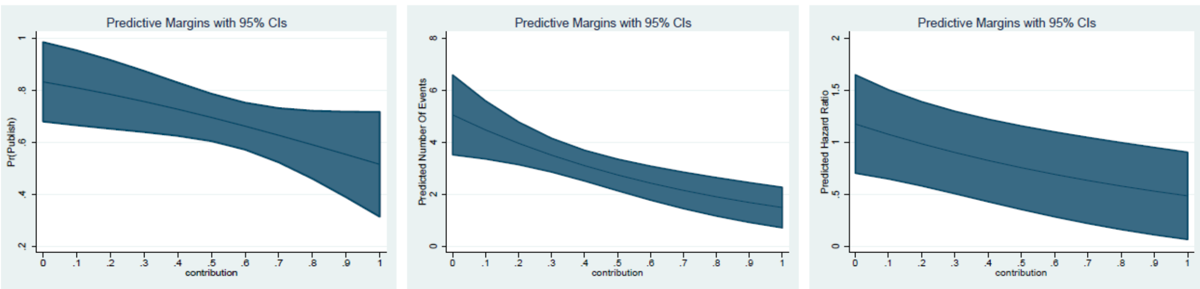
The publication rate increases by 210% if a project is a knowledge generation project, 229 % if a project is an ideas testing project and 102 % if a project is a technology development project compared to a problem solving project (model 1). When the proportional contribution is included the estimated publication rate increase is 82%, 101 %, and 49% respectively. The publication rate decreases by 5.9 % for each percentage point increase in firm contribution (model 2 (6.2 % in model 4)).

Firm contribution and the likelihood, amount and timing of project related publications

Proposition 3 (*The degree of firm participation and contribution relates to the degree to which projects lead to project-related publications*) is examined in all three regressions (table 5, 6 and 7) by the including a measure of firm contribution to the project.

The relative contribution to the project by firms is negatively related to the probability, amount and timing of publication. In figure 4 the predicted probability of a project-related publication, the amount of publications and hazard ratio of publication for a given value of firm contribution is illustrated (based on regression model 3). It shows how the likelihood, number and hazard ratio of publication is decreasing in firm contribution. The expected number of publications falls within the 95 % confidence interval of 2.1 to 3.2 publications for projects where firms contribute 50 % in cash or in kind. The interval is .7 to 2.2 publications when projects are fully funded by firms and 3.3 to 5.4 publications when firms contribute 10 % to the project.

Figure 4: Predictive margins of contribution on project-related publication outcomes



Note: Predictive margins of contribution on the probability to publish (left) number of publications (centre) and hazard ratio of publishing (right). Shaded area indicate 95% Confidence intervals. Table A2 contains the predicted margins on which the illustrations are based.

Finalization and contribution moderately correlate in the data, and including the measure of firm contribution reduces the estimated effect sizes and significance of finalization. The variables can on the one hand be argued to be interrelated, as projects with a high degree of finalization are often highly subsidized by partner firms. On the other hand, finalization and firm contribution cannot be argued to be fully interdependent. A project can for example be funded entirely by a firm and still have a low degree of finalization e.g. a research project sponsored by a firm.Hence, the interpretation of whether finalization is related to publication outcomes should be seen in the context of which co-variates are included in the analysis.

Discussion

Despite descriptive differences in the mean propensity to publish between the four project types, I find that when taking variation and relevant control variables into account there is no significant difference in the propensity to publish between projects of low to moderate levels of finalization. Only projects with a high degree of finalization (problem solving projects) lead to publication of project related publication considerably less often. When it comes to the number of project related publications, there is a higher degree of difference between projects. Problem solving projects lead to fewer publications than projects with a lower degree of finalization and knowledge generation projects lead to a significantly higher number of publications than both technology development projects and problem solving projects. The timing of the first publication is significantly faster for knowledge generation projects and ideas testing projects compared to problem solving projects but is not significantly different from technology development projects.

The central argument in Perkmann and Walsh is that higher degrees of finalization is related to secrecy and relevance issues. Academics then do not pursue academically relevant research, postpone or forego publication of academically relevant findings. The pattern in the sample of projects studied here however, does not indicate that project finalization and publication behaviour has a proportional relationship as described in Perkmann and Walsh. As soon as a university-industry project is one step removed from pure consultancy the differences in publication behaviour are only marginal. Thus, whether the project focuses on technology development, ideas testing or knowledge generation only to a limited extent relates to project-related publication outcomes.

It should be noted that there are a number of differences between this study and that of Perkmann and Walsh. The key differences are the sample selection and the type of data selected.Perkmann and Walsh's study relied on self-reported projects from a sample of highly engaged scholars within engineering and the physical sciences and was limited to ex ante self-reported publication behaviour. This sample consists of projects from a wider set of disciplines and with a more diverse set of academics engaged in them. While these differences may complicate comparison, I argue that the data in this study is well suited to critically analyse the proposition and succeeds in showing that at least in this context project finalization is not a major driver in the differences in publication outcomes.

The analyses indicate that while finalization can predict some variation in publication outcomes, the degree of economic contribution and practical participation of firms is an important parameter for predicting publishing outcomes in university-industry projects. The higher the contribution and participation from firms, the lower the probability that the project leads to publications, the lower the number of project related publications and the longer time until the first project related publication is published. This relationship holds both for analysis with and without including measures of finalization.

The notable relationship between contribution and publication outcome may reflect that when firms are highly involved in projects they are able to influence, to a higher degree, the process and outcomes of projects. Thus, when projects lead to commercially interesting outcomes, irrespective of the initial objective, firms may exert a higher degree of control over how, when and whether findings are published. Firms may also be more interested in funding and participating in projects where they expect commercial opportunities. These projects will then be more directed towards application and commercialization, while firms may be more inclined to be a minority participant in projects are more strategic and long-term for the firm.

The results suggest that academic project participants appear to be able to pursue research relevant to their field in projects where publishable research is not the primary objective. It indicates that researchers co-design projects and opt into projects that have the potential to generate knowledge and enable discoveries relevant to their field. The frequency of publication regardless of finalization can theoretically be explained by the institutional incentive to publish continuously in order to remain employed in the academic system (Stephan, 2004).

While the sample here is diverse in terms of discipline and researcher seniority, the generalizability of the findings is still constrained by a number of factors, such as the moderate sample size, the potential omission of relevant control variables and the fact that all projects take place within one university in Denmark. However, while there may be local specificities with regard to the university, regional and national landscape, academia tends to transcend these boundaries and it is likely that collaborative and publication behaviour is effected mainly by the disciplinary cultures than by national and local circumstances.

Conclusion

In this study, I divide 117 projects into four types based on their degree of finalization and investigate whether publication outcomes differ between the four project types. The aim is to revisit the proposition of Perkmann and Walsh that the degree of finalization of a project is decisive for the dissemination of knowledge outcomes from university-industry projects.

The results of this study indicate that the degree of finalization relates moderately to whether or not projects lead to publications, how many publications a project leads to and when project-related findings are published. The most consistent difference in publishing outcomes is between problem solving projects and the three remaining project types. Thus, the expectation is that projects focused on solving problems for firms will generally lead to publications less often, a lower number of project-related publications, and that publications are published with a higher delay than other project types. There are on the other hand, rather small differences in publication outcomes between projects focused on generating knowledge of a phenomenon or relationship and projects aiming at assessing feasibility of or developing commercial ideas and technologies. Finally, the study finds that the degree of firm contribution and participation in projects is negatively related to project related publication outcomes.

This study is in part a conceptual replication study, an attempt to revisit the study of Perkmann and Walsh (2009) by applying the proposed model to a different set of data with a different methodology to assess whether the propositions are observable in a different context. There are aspects that differ considerably between the two studies, however, I argue that this study informs whether the proposed model is relevant in another setting and is applicable outside the scope in which it was devised and formulated.

This study contributes by providing comparative evidence to the study of Perkmann and Walsh (2009). It provides a larger sample, a quantitative estimation of the proposed relationship and information not only on the number of publications related to university-industry projects but also the occurrence and timing hereof. The study demonstrates how university-industry projects can be linked directly to revealed publication behaviour, where studies in the past have relied on self-reported outcomes.

References

Arza, V. (2010). Channels, benefits and risks of public-private interactions for knowledge transfer: conceptual framework inspired by Latin America. *Science and Public Policy, 37*(7), 473-484. doi:10.3152/030234210x511990

Banal-Estanol, A., Macho-Stadler, I., & Perez-Castrillo, D. (2013). Research Output From University-Industry Collaborative Projects. *Economic Development Quarterly, 27*(1), 71-81. doi:10.1177/0891242412472535

Blumenthal, D., Campbell, E. G., Causino, N., & Louis, K. S. (1996). Participation of life-science faculty in research relationships with industry. *New England Journal of Medicine, 335*(23), 1734-1739. doi:10.1056/nejm199612053352305

Caloghirou, Y., Tsakanikas, A., & Vonortas, N. S. (2001). University-industry cooperation in the context of the European Framework Programmes. *Journal of Technology Transfer, 26*(1-2), 153-161.

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2002). Links and Impacts: The Influence of Public Research on Industrial R&D. *Management Science, 48*(1), 1-23. doi:10.1287/mnsc.48.1.1.14273

Caron, E. and van Eck, N.J. (2014). Large scale author name disambiguation using rule-based scoring and clustering Context counts: Pathways to master big data and little data, In: Proceedings of the Science and Technology Indicators Conference, Leiden (2014) pp. 79–86.

D'Este, P., & Perkmann, M. (2011). Why do academics engage with industry? The entrepreneurial university and individual motivations. *Journal of Technology Transfer, 36*(3), 316-339. doi:10.1007/s10961-010-9153-z

Dasgupta, P., & David, P. A. (1994). TOWARD A NEW ECONOMICS OF SCIENCE. *Research Policy, 23*(5), 487-521.

De Fuentes, C., & Dutrenit, G. (2012). Best channels of academia-industry interaction for long-term benefit. *Research Policy, 41*(9), 1666-1682. doi:10.1016/j.respol.2012.03.026

Florida, R. (1999). The role of the university: Leveraging talent, not technology. *Issues in Science and Technology, 15*(4), 67-73.

Goldfarb, B. (2008). The effect of government contracting on academic research: Does the source of funding affect scientific output? *Research Policy, 37*(1), 41-58. doi:10.1016/j.respol.2007.07.011

Gulbrandsen, M., & Smeby, J. C. (2005). Industry funding and university professors' research performance. *Research Policy, 34*(6), 932-950. doi:10.1016/j.respol.2005.05.004

Laursen, K., & Salter, A. (2004). Searching high and low: What types of firms use universities as a source of innovation? *Research Policy, 33*(8), 1201-1215. doi:10.1016/j.respol.2004.07.004

Levy, R., Roux, P., & Wolff, S. (2009). An analysis of science-industry collaborative patterns in a large European University. *Journal of Technology Transfer, 34*(1), 1-23. doi:10.1007/s10961-007-9044-0

Lin, M. W., & Bozeman, B. (2006). Researchers' industry experience and productivity in university-industry research centers: A "scientific and technical

human capital" explanation. *Journal of Technology Transfer, 31*(2), 269-290. doi:10.1007/s10961-005-6111-2
Morandi, V. (2013). The management of industry-university joint research projects: how do partners coordinate and control R&D activities? *Journal of Technology Transfer, 38*(2), 69-92. doi:10.1007/s10961-011-9228-5
Nunez-Sanchez, R., Barge-Gil, A., & Modrego-Rico, A. (2012). Performance of knowledge interactions between public research centres and industrial firms in Spain: a project-level analysis. *Journal of Technology Transfer, 37*(3), 330-354. doi:10.1007/s10961-010-9178-3
Perkmann, M., Salandra, R., Tartari, V., McKelvey, M., & Hughes, A. (2021). Academic engagement: A review of the literature 2011-2019. *Research Policy, 50*(1), 104114. doi:https://doi.org/10.1016/j.respol.2020.104114
Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Brostrom, A., D'Este, P., . . . Sobrero, M. (2013). Academic engagement and commercialisation: A review of the literature on university-industry relations. *Research Policy, 42*(2), 423-442. doi:10.1016/j.respol.2012.09.007
Perkmann, M., & Walsh, K. (2007). University-industry relationships and open innovation: Towards a research agenda. *International Journal of Management Reviews, 9*(4), 259-280. doi:10.1111/j.1468-2370.2007.00225.x
Perkmann, M., & Walsh, K. (2009). The two faces of collaboration: impacts of university-industry relations on public research. *Industrial and Corporate Change, 18*(6), 1033-1065. doi:10.1093/icc/dtp015
Ramos-Vielba, I., Fernandez-Esquinas, M., & Espinosa-de-los-Monteros, E. (2010). Measuring university-industry collaboration in a regional innovation system. *Scientometrics, 84*(3), 649-667. doi:10.1007/s11192-009-0113-z
Rentocchini, F., D'Este, P., Manjarrés-Henríquez, L., & Grimaldi, R. (2014). The relationship between academic consulting and research performance: Evidence from five Spanish universities. *International Journal of Industrial Organization, 32*, 70-83. doi:https://doi.org/10.1016/j.ijindorg.2013.11.001
Schartinger, D., Rammer, C., Fischer, M. M., & Frohlich, J. (2002). Knowledge interactions between universities and industry in Austria: sectoral patterns and determinants. *Research Policy, 31*(3), 303-328. doi:10.1016/s0048-7333(01)00111-1
Stephan, P. E. (1996). The economics of science. *Journal of Economic Literature, 34*(3), 1199-1235.
Stephan, P. E. (2004). Robert K. Merton's perspective on priority and the provision of the public good knowledge. *Scientometrics, 60*(1), 81-87. doi:10.1023/b:scie.0000027311.17226.70
Ziman, J. (2000). *Real Science: What it Is and What it Means*. Cambridge: Cambridge University Press.

Appendix

Table A1

	Problem solving				Technology development				Ideas testing				Knowledge generation				All projects			
	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max
Budget (1000 DKK)	695.26	1144.13	25.07	4372.01	12904.61	14316.16	197.92	60489.98	13038.93	12317.12	455	40338.59	7537.39	8359.38	120	33109	9768.17	11841.63	25.07	60489.98
Duration (Months)	12.48	7.80	3.93	36.5	31.40	12.25	3.8	48.7	36.37	13.24	3.33	60.90	31.22	17.01	1.5	60.87	30.20	15.29	1.50	60.90
Organisations	2	0	2	2	4.3	2.73	2	13	5.1	3.08	2	12	3.7	2.15	2	8	4.0	2.63	2	13
Firms	1	0	1	1	2.4	1.76	1	9	2.6	1.90	1	7	1.6	1.40	1	7	2.0	1.67	1	9
Research Organisations	1	0	1	1	1.9	1.47	1	7	2.3	1.58	1	7	2	1.70	1	7	1.9	1.51	1	7
Firms tasks (proportion)	0	0	0	0	.39	.29	0	.93	.20	.22	0	.78	.14	.19	0	.87	.21	.26	0	.93
AU Tasks (Proportion)	1	0	0	0	.50	.34	.04	1	.59	.33	.05	1	.70	.19	.08	1	.65	.34	.04	1
Other res orgs Tasks (Proportion)	0	0	0	0	.11	.17	0	.59	.21	.23	0	.69	.17	.27	0	.88	.14	.22	0	.88
Third party funding (Proportion to budget)	0	0	0	0	.47	.22	0	.77	.53	.29	0	.89	.46	.35	0	1	.43	.32	0	1
Firm funding (Proportion to budget) (in-kind and in cash)	.99	.03	.90	1	.38	.26	.05	1	.30	.29	.02	1	.36	.37	0	1	.43	.36	0	1
Cash contribution and budgeted tasks (proportion of budget)	.99	.03	.90	1	.54	.26	.11	1	.36	.29	.04	1	.39	.36	0	1	.51	.35	0	1

Table A2

Probability of publishing - regression model 3.				
Contribution	Margin	Std. Error	95 % CI	
0.0	.8317744	.0777864	.6793159	.9842329
0.1	.8088313	.0734181	.6649346	.9527281
0.2	.7836606	.0673237	.6517085	.9156126
0.3	.7562692	.0599103	.6388472	.8736912
0.4	.7267188	.0522262	.6243573	.8290803
0.5	.6951312	.0464667	.6040582.	7862041
0.6	.6616907	.0460071	.5715184	.751863
0.7	.6266438	.0530954	.5225788	.7307089
0.8	.5902942	.0665673	.4598246	.7207638
0.9	.5529943	.0838135	.388723	.7172657
1.0	.5151332	.1027198	.3138061	.7164604
Number of publications - regression model 3.				
Contribution	Margin	Std. Error	95 % CI	
0.0	5.050207	.7814743	3.518546	6.581869
0.1	4.470669	.5683151	3.356792	5.584546
0.2	3.957636	.417705	3.138949	4.776323
0.3	3.503476	.3302264	2.856244	4.150708
0.4	3.101433	.3006004	2.512267	3.690599
0.5	2.745527	.3090243	2.139851	3.351204
0.6	2.430463	.3324351	1.778902	3.082024
0.7	2.151554	.3568787	1.452085	2.851024
0.8	1.904652	.3765358	1.166655	2.642649
0.9	1.686083	.3896889	.9223068	2.449859
1.0	1.492596	.3963571	.7157501	2.269442
Hazard ratio of publishing - regression model 3.				
Contribution	Margin	Std. Error	95 % CI	
0.0	1.174889	.2407992	.7029308	1.646846
0.1	1.075535	.2181584	.6479525	1.503118
0.2	.9845834	.2061497	.5805373	1.388629
0.3	.9013229	.201733	.5059335	1.296712
0.4	.8251033	.2019573	.4292743	1.220932
0.5	.7553291	.2044777	.3545602	1.156098
0.6	.6914554	.2076909	.2843887	1.098522
0.7	.632983	.2106185	.2201784	1.045788
0.8	.5794553	.2127241	.1625237	.996387
0.9	.5304542	.2137568	.1114985	.9494099
1.0	.4855968	.2136396	.0668708	.9043227

Chapter 6: Similarity of academics' research output produced with and without firm involvement

Abstract

It is a frequently voiced that the participation of firms in academic research may affect the direction of research. Yet, limited empirical research has investigated to what extent research produced and published with industry differs from that performed in an academic context. This study investigates the degree to which publications produced by engaged academics within university-industry projects differ in terms of content and knowledge base from their published research in general. Exploiting a database of academics engaged in university-industry projects, this study compares the similarity of publications produced by academics in two different contexts. Measures include text based and bibliographic based cosine similarity measures. The study of a sample of 115 academics and their publication portfolio shows that the academics' publications within university-industry projects tends to be peripheral to academics' remaining publication portfolio. This relationship is more pronounced in applied fields of science. I illustrate the regression results by mapping the publication portfolios of select academics. In the study, I discuss the limitations and generalizability of the findings in the final section of the article.

Introduction

University-industry collaboration has become an increasingly important activity in academia and is an issue that has received growing attention over the past decades within the scholarly community (Bozeman, Fay, & Slade, 2013; Markus Perkmann, Salandra, Tartari, McKelvey, & Hughes, 2021; M. Perkmann et al., 2013; M. Perkmann & Walsh, 2007). Research collaboration may have a number of potential benefits and drawbacks for academic research (Katz & Martin, 1997). Among the potential benefits for public-private collaboration in particular, are a greater utilization of academic research in business innovation, knowledge transfer and exchange, mutual learning, and a greater alignment of academic and business research (D'Este & Perkmann, 2011; Dutrenit, De Fuentes, & Torres, 2010). However, concerns have been raised that a focus on bridging academic and entrepreneurial research may lead to an overly short-term focus on reaping immediate benefits, which may ultimately result in a slowing of the growth of scientific knowledge. Connected to this are a number of other potential negative implications, such as an excessive shift from fundamental to applied research, less academic freedom (Behrens & Gray, 2001), manipulation of science for short term gain (Slaughter & Leslie, 2001) and restrictions on the diffusion of open knowledge. At the level of the academic, the concerns are that academics may become less productive in terms of scholarly output, delay or suppress relevant knowledge, are steered towards more application-oriented and commercial research objectives and that their research quality may be adversely affected (M. Perkmann et al., 2013).

Despite fears that academic engagement in university-industry research may slow knowledge diffusion and increase short-term commercial focus of research, studies generally find that academics who engage with industry are slightly more productive than their non-engaging peers (Aschhoff & Grimpe, 2014; Bekkers & Freitas, 2008; Gulbrandsen & Smeby, 2005). Moreover, that productivity is not adversely affected by academic engagement (Bikard, Vakili, & Teodoridis, 2019; Blumenthal, Campbell, Causino, & Louis, 1996; Goldfarb, 2008; Gulbrandsen & Smeby, 2005; Lin & Bozeman, 2006). Although, studies have found that some forms of engagement are associated with a lower level of productivity (Hottenrott & Thorwarth, 2011), and that publishing may have an inverse U-shape-relationship with engagement (Lin & Bozeman, 2006). Similarly, a number of recent studies have analyzed the relationship between engagement and scientific impact though without reaching any clear conclusion (Markus Perkmann et al., 2021).

Although, academic productivity seems largely unaffected by engagement, the content of the academics' research with industry may differ from their purely academic work in terms of objective, topic, methodology and direction of research. University-industry collaboration may influence academics' selection of topics and methodologies (Florida & Cohen, 1999). For example, there is a question of whether engagement with firms may push academics towards more applied research (e.g. (Van Looy, Callaert, & Debackere, 2006), and affects the direction of academic research, though there is limited evidence on this issue. In their review, Markus Perkmann et al. (2021) state that "We also need to learn more about the effects on the direction of research, beyond the question of whether engagement pushes academics towards more applied research, for which there is little evidence".

Few studies have attempted to investigate whether the academics' research focus shifts when they engage with industry. Blumenthal et al. (1996) finds that US life science academics with industry support are more likely to report that their choice of research topic is influenced by the projects' commercial potential. Van Looy et al. (2006) finds that academic inventors do not shift towards publishing in more applied journals after participating in inventorship compared to their non-inventing peers (Van Looy et al., 2006).

Academics may tend to pursue different topics and objectives *in different settings* (e.g. more short-term focused or application oriented in projects with industry). (Godin & Gingras, 2000) suggest that it is generally the same researchers who engage in both industry collaboration and "basic" research. In this reasoning, some academics continually go back and forth between basic or fundamental science and applied science. This would imply that the type of research outcomes would differ based on whether academics collaborate with industry or without. However, academics who are engaged in topics and methodologies that are of interest to industry may be more likely to receive industrial funding and to participate in university-industry collaborations, which would mean that engaged academics' research objectives and topics would be similar with and without industry involvement. Two of the most frequently reported reasons for academics to collaborate are to secure funds for graduate students and lab equipment, and to supplement funds for their academic research (Lee, 2000; Tartari & Breschi, 2012). This re-enforces the expectation that academics already active within specific topics and areas of interest to industry may use industry projects to access funding and other assets (materials, know-how etc.) to support their current research agenda. On the other hand, the available funding from industry may also motivate academics to change research direction and focus temporarily in order to secure funds. Finally, the notion that collaboration may lead to mutual learning and cross – fertilization and innovation points to another possible mechanism; namely, that research outcomes are likely to be different because of the process and context of a university-industry project and not necessarily because of the pursuit of a different agenda or topic.

This paper examines to what extent published research produced in the context of university-industry projects is similar to the overall research profile of the engaged academic. This paper focuses specifically on the extent publications linked to university-industry projects are measurably similar to publications the engaged academic produces otherwise. I compare academic publications published by academics produced within and outside of university-industry projects using two measures of research content similarity: text similarity and bibliographic coupling. Specifically, I measure the similarity of publication pairs authored by the same academic. Text similarity measures the extent to which abstracts and titles of publications share similar vocabulary (Dillon, 1983) while bibliographic coupling is used to measure publication similarity assuming that the more common references that publication pairs share, the more they draw on the same knowledge base (Kessler, 1963; Vladutz & Cook, 1984). In addition to similarity measures, I investigate whether the citation impact and collaboration patterns relate to the context in which the publication is produced.

Method and data:

The study utilizes a dataset of university-industry projects involving academics from the Faculty of Science and Technology at Aarhus University. Projects are identified through the internal university-database, Inteum. The database contains detailed information on project characteristics such as funding, budgets and participants. Using this information, I compiled publication lists for academic project participants, identifying publications linked to university-industry projects (referred to as industry publications) and participants' entire portfolio of publications outside the university-industry projects (referred to as portfolio publications).

The projects vary in terms of length, objectives and funding. Projects were initiated between 2010-2014 and ended between 2010 and Dec 31st, 2017. All university-industry projects must be registered with the university's technology transfer office, hence the Inteum database should include all academics employed at the university that were engaged in industry projects in the period 2010-2014. However, the dataset used here does not contain information on whether the academics also were engaged in projects which begin prior to 2010 or after 2014.

For each academic, industry publications are identified as well as their entire research portfolio from their first publication to their last. Publications were identified in Web of Science, thus publications not indexed by the Web of Science are not included. Publications include journal publications, review articles and letters. The dataset includes in 219 academics who participate in one or more of the 117 unique university-industry projects. In order to conduct the analysis, I require that academics have published at least one industry publication and at least four portfolio publications. This yielded a sample of 115 academics for this study. While this data is needed to make comparisons, it also affects the composition of the sample. For example, early career researchers, who frequently have less than four journal articles, are excluded, as are researchers that have not published any journal articles relating to a university-industry project. Thus, academics only involved in certain types of projects that are less likely to lead to publishable results may be under-represented.

While not without its limitations, the data provides a strong basis for comparison of the content of research in UIPs compared to academics' primary research. A number of studies compare industry co-authored publications to academic co-authored publications (Bloch, Ryan, & Andersen, 2019; Lebeau, Laframboise, Lariviere, & Gingras, 2008). They do not fully capture outputs from actual collaborations; instead, they assume that industry co-authorships often occur as a result of collaboration or similar interaction. It is likely however, that co-publications with industry occur more frequently within some sciences than others for a given level of collaboration. And, as I show below, many project related publications are not co-authored by the industry partner. Instead, partner firms are mentioned directly in the acknowledgements or indirectly through acknowledging the funder of the project.

As a first step, I compiled a list of publications for each academic involved in a project using the author disambiguation algorithm in the Centre for Science and Technology Studies (CWTS) enhanced version of the Web of Science database (Caron & van Eck, 2014). The full name and e-mail of academic project participants were used to identify each academic's publication lists. Publication lists were then manually validated by comparing sample publications to university-profiles and online CVs. From the full lists of web of science covered journal publications, industry publications were identified based on one of the following criteria. First, a publication acknowledges one of the projects, which the academic is involved in, by name, acronym and/ or grant number in the acknowledgements of the publication. Second, the funder of the project or the partnering firm is mentioned in the acknowledgements or the partnering firm is a co-author *and* the content of the abstract, acknowledgements and title are similar to the content of the project description or in other ways points to a direct link between the project and publication. If the publication fits one of the two steps, I assume it is an industry publication. This method is described in greater detail in Chapter 5.

The categorization of publications as industry publications and portfolio publications is not without caveats. Industry publications are publications that are directly related to projects the engaged academic has participated in. However, I am unable to verify whether portfolio publications are a result of purely academic collaboration or from industry participation. Therefore, portfolio publications, especially those published in the period before the first observed project, may contain industry-related publications. The enhanced version of Web of Science has an indicator of industry co-authorship (p_indsutry), based on author affiliations. As a robustness test, the analysis is also conducted where all portfolio publications with an industry co-author are also categorized as university-industry publications. This, however, means that university-industry publications in the robustness test may include publications that do not arise from collaborations within university-industry projects.

As mentioned above, I measure publication similarity through two approaches: text similarity and bibliographic coupling. In both cases, I analyze the degree of similarity between industry and portfolio publications (industry-portfolio pair) compared to the similarity of portfolio publications (portfolio pairs). If research within university-industry projects is similar to the research that academics generally pursue, then the expectation is that the average similarity between industry-portfolio pairs will be equal to the average similarity between portfolio publication pairs.

I analyze to what extent industry-portfolio publication pairs are similar (in terms of text similarity and bibliographic coupling) compared to portfolio publication pairs. I present the analysis in two ways: First, I calculate academic level indicators of average cosine similarity for industry-portfolio pairs, industry pairs and portfolio pairs and compare averages. Second, I perform regression analyses at the publication-pair level. Cosine similarity (text or bibliographic coupling based) is predicted by two dummy variables: industry-portfolio pairs (IP pairs) and industry pairs (II-pairs).

For the calculation of text similarity between two publications, each term is notionally assigned a different dimension and a document is characterized by a vector where the value in each dimension corresponds to the number of times the term appears in the document. Cosine similarity provides a useful measure of how similar two documents, based on their abstracts and titles, are likely to be in terms of their subject matter. I calculate the cosine similarity between documents in each of the 115 academic's publication portfolios based on the title and abstracts of publications. I process the text data by first removing stopwords and then by stemming terms so that terms such as "probability" and "probabilities" are treated as one term "probabil*". Based on the reduced and stemmed term list, I construct a document-term matrix that counts the number of occurrences of a term in a document. The cosine similarity between two documents is calculated based on the degree of co-occurrence of the same terms.

Bibliographic coupling occurs when two works reference a common third work in their bibliographies. Two documents are bibliographically coupled if they both cite one or more of the same documents. A high level of bibliographic coupling is an indication that two works treat a related subject matter. While the interpretation of bibliographic coupling is quite intuitive, a bibliographic coupling is merely an indication of the existence of the probability, value unknown, of a relationship between two documents rather than a constant unit of similarity (Martyn, 1964). Thus, the co-occurrence of a reference may indicate different levels of similarity depending on the reference and context. Bibliographic coupling is similar to text similarity, where it is the co-occurrence of references instead of terms that are of interest. Cosine similarity provides an indication of how similar the two documents are in terms of their knowledge bases.

Table 1 below shows some basic statistics for the sample. 70 % of the sample are at the associate professor or professor level at the time of their first project, 20 % are at the assistant professor level. The remaining academics are either PhDs or technical staff at the time of their first project. On average, academics participate in 1½ projects in the observed period with an average total project duration of 52 months. Academics are affiliated to all the departments at the Faculty except mathematics where no university-industry projects were registered in the observed period. The main departments represented in the sample are Animal science, Agroecology, Engineering, Food science and Nanoscience.

Table 1: Sample characteristics of engaged academics

Distribution of academics by position					
Variable	Professor	Associate Professor	Assistant Professor	PhD	Other
Position	.19	.50	.18	.05	.07
Distribution of academics across discipline					
Agroecology	Animal Science	Bioscience	Chemistry	Computer Science	Engineering
.16	.15	.04	.06	.02	.17
Environmental science	Food Science	Geoscience	Molecular Biology and Genetics	Nanoscience	Physics
.01	.12	.09	.10	.12	.04
Statistics for university-industry projects					
Variable		Mean	Std. error	95 % CI	
Number of projects		1.48	.08	1.31	1.64
Total duration of projects (months)		52.3	3.1	46.1	58.4
Number of portfolio publications		67.8	8.2	51.6	84.0
Number of industry publications		4.7	.48	3.8	5.7

Table 2 contains the averages over the sample of 115 academics for each of the two groups of publications. For each academic, I compare the two sets of publications (project related publications and portfolio publications) in terms of their average citation impact (MNCS), journal impact (MNJS), proportion of collaborative publications (pp_collab), proportion international collaborative publications (pp_int_collab) and the average number of authors.

The mean normalized citation score (MNCS) indicator is obtained by averaging the field normalized citation scores of all publications of the academic. If an academic has an MNCS indicator of one, the publications of the academic have been cited on par with world averages (or more precisely, database averages) for similar publications in terms of research field and publication year (Waltman et al., 2012). In calculating citation impact, I apply variable citation windows running from the year publication (included) until 2019. An equivalent method is used to calculate the mean normalized journal score (MNJS) for journal impact.

Table 2: Collaboration and impact indicators of publication portfolios by type of publication

Variable	Mean	Std. error	95 % CI	
PP collab (industry pubs)	.71	.03	.65	.77
PP collab (portfolio pubs)	.64	.02	.61	.67
PP int collab (industry pubs)	.39	.03	.32	.45
PP int collab (portfolio pubs)	.41	.02	.37	.45
PP_industry (industry pubs)	.21	.03	.15	.27
PP_industry (portfolio pubs)	.10	.11	.07	.12
MNCS (industry pubs)	1.07	.08	.91	1.23
MNCS (portfolio pubs)	1.30	.05	1.19	1.41
MNJS (industry pubs)	1.29	.04	1.21	1.37
MNJS (portfolio pubs)	1.29	.03	1.22	1.36

To examine whether the collaboration patterns differ in the two contexts. I use proportion of publications with at least two institutional addresses, proportion of publications with at least one institutional address outside of Denmark, and the average number of authors of a publication.

On average, industry publications are slightly more collaborative and have a higher number of authors than publications in the academics remaining portfolio. Industry publications and portfolio publications are on average published in similar level journals, measured by MNJS. The indicators show that the characteristics of publications are similar when it comes to collaboration patterns and journal impact level. The main difference between the two groups is the citation impact of articles. Academics tend to receive 25 percentage points fewer normalized citations for their industry publications compared to portfolio publications. Studies have used the Journal impact factor to compare the “quality” of industry and non-industry publications they find that there is no difference in the “quality” of research on the basis of similar levels of JIF (e.g. (Lebeau et al., 2008)). The results in this sample show that journal impact does not necessarily equate to the actual number of citations received by articles and that concluding equal quality on this basis is unfounded (Larivière & Sugimoto, 2019).

Results - Difference in similarity for UIP project publications

To assess whether research published in relation to university-industry projects differ from academics’ remaining publication portfolio, I calculate and compare the average cosine similarity based on text and references between all industry publication pairs (II), portfolio publication pairs (PP) and industry-portfolio publication pairs (IP). The table below (Table 3) shows the average similarities for the three types of publication pairs.

The cosine similarity based on bibliographic coupling reflects the similarity between two documents based on the number of common references. The majority of publication pairs have no references in common. Therefore, the average cosine similarities tend towards zero and the distribution is highly skewed, with a high proportion of zero values and a long tail for positive values. The average cosine similarity between portfolio publication pairs (PP) is .039, while the average cosine similarity between industry-portfolio pairs (IP) is .029. On average, portfolio publication-pairs have a cosine similarity that is higher than industry-portfolio-pairs. In absolute terms, the difference is rather small, while the percentage difference is high. The difference may reflect significant difference in the tail of the distribution, a difference in the number of pairs with no common references or a combination. Industry-pairs (II) have a substantially higher average similarity than both Portfolio- and Industry-Portfolio-pairs (.15). Academics’ industry publications thus tend to be more similar to each other than academics’ portfolio publications. This result is not surprising as many of the industry publications are related to the same project and produced within a similar timeframe.

The cosine similarity based on titles and abstracts reflects the similarities between two documents based on the number of common terms. The average cosine similarity between PP pairs is .21 and .20 for IP pairs while it is .38 for II pairs. Based on term co-occurrences, the descriptive statistics indicate that on average industry publications are as similar to portfolio publications as portfolio publications are to each other.

The descriptive statistics of bibliographic similarity indicate that industry publications are slightly dissimilar to portfolio publications relative to how similar portfolio publications are to each other. Yet, based on term co-occurrence, the level of similarity for the two comparisons similar. Thus, publications related to UIPs are similar to publications in the academics' portfolios in general. Conclusions can, however, not be drawn on the basis of these averages. The average similarity for publication pairs can vary greatly between academics. Absolute differences of for example 0.1 in cosine similarity between two groups of publication pairs may be a large difference for some academics while it is a small difference for others. Therefore, that the overall difference in mean cosine similarity is low can be a result of the variance in the general level of similarity between publication pairs. In the regression analysis below, such variance, is taken into account by employing academic fixed effects, among other confounding variables.

Table 3: Similarity indicators of publication pairs of by type of publication pair

Variable	Mean	Std. error	95 % CI	
Bibliographic coupling				
Mean cosine similarity portfolio-portfolio (PP) pairs	.039	.003	.033	.046
Mean cosine similarity industry-portfolio (IP) pairs	.029	.003	.024	.035
Mean cosine similarity industry-industry (II) pairs*	.15	.012	.123	.170
Text similarity				
Mean cosine similarity portfolio-portfolio (PP) pairs	.21	.01	.19	.23
Mean cosine similarity industry-portfolio (IP) pairs	.20	.01	.18	.22
Mean cosine similarity industry-industry (II) pairs**	.38	.02	.35	.41

Note: Only 98*, 91** academics have multiple industry publications.

Regression publication pair analysis.

In this section, I investigate the relationship between context of publication (with and without industry involvement) and similarity between pairs of publications authored by an engaged academic. I do so in a Pseudo-poison-maximum log likelihood model. The Pseudo poison maximum likelihood model is often used in gravity equations in economics in order to work with data that is zero-inflated and follows a log normal distribution for positive integers (Motta, 2019). Pairwise cosine similarity follows a similar distribution. The unit of analysis is publication pairs authored by the same academic. The number of observations is the total number of pairings of publications for each of the 115 academics (e.g. for an academic with a portfolio of 10 publications, the number of publication pairs is (10*(10-1))/2=45). I account for academic fixed effects as well as the absolute time between publications of publications. In separate regressions, I assess the relationship within disciplines that are often referred to as applied and basic or fundamental.

In total, I present six regressions in table 4. In the first three regressions, the dependent variable is the cosine similarity between two documents based on term co-occurrence in titles and abstracts. In the fourth to sixth regression, the dependent variable is the cosine similarity between two documents based on their degree of bibliographic coupling. Regression one and four is performed on the full set of academics while regression two, five, three and six are performed on subsets of the academics. Regression two and five include all academics in "applied" disciplines and regression three and six include all academics in "basic" or "fundamental" disciplines.

The categorization of applied and basic is a rough approximation of what is generally thought of as applied while the "basic" category is made up of fields that are not generally referred to as applied. I categorize academics in one of the two categories based on their departmental affiliation. The applied academics are affiliated to the following departments: Agroecology, Animal Science, Engineering, Environmental Science, Food Science and Nanoscience. The basic academics are affiliated to the following departments: Physics and astronomy, Molecular Biology and Genetics, Geoscience, Computer Science, Chemistry and Bioscience

The explanatory variables include two binary variables indicating whether the publication pair consists of 1) two publications related to a university industry project (II-pair) or 2) one publication related to a project and the other not project related (IP-pair)- where the base case is a publication pair consisting of two publications are not project related (PP-pair). The coefficient of "IP-pair" is interpreted as the percentage difference in the expected cosine similarity if a publication pair consists of one project related and one non-related relative to the expected cosine similarity if both publications are not project related. A large negative coefficient will thus indicate that publications pairs from two different contexts have a lower expected level of similarity than two publications from similar contexts. I include two control variables: 1) the publication gap in years between publication pair and 2) fixed effects for academics. The reason for including the time gap is that publications published close to each other may be more likely to be similar. Academics may focus on certain subjects and research problems for periods of time and over time shift towards other research problems. Moreover, the same projects may lead to a string of related publications published within a short period of time. Concerning fixed effects, since similarity is calculated for each academic, independent of each other, the mean similarity between publication pairs will vary dependent on the academic. Including fixed effects adjusts for this.

The drawback of this approach is that academics with a high number of publications will have a higher number of publication pairs and the estimates will be weighted. If the number of publications an academic has produced is related to the type of research the academic engages in, the estimates will be biased up or down.

Similarity in terms of text and bibliographic coupling

The expected text-based cosine similarity is 35 % (calculated as the exponential of the coefficient ".279") higher when both publications are project related and 11 % lower when the publication pair consists of one project related and one non-related compared to a publication pairs consisting of non-project-related publications. The expected bibliographic coupling-based cosine similarity is 53 % higher when both publications are project related and 14 % lower when the publication pair consists of one project related and one non-related publication compared to publication pairs consisting of non-project-related publications. Thus, when an academic produces a publication in an industry project, it is more likely to be similar to the academic's other industry publications than to a non-project publication. A pair of portfolio publications have a higher expected similarity than an industry – portfolio publication pair. This indicates that publications produced in an industry context are more likely to be peripheral to the publications produced outside university-industry projects.

Differences between basic and applied fields

The subsample regressions two and three indicate that the expected cosine similarity of publication pairs from different contexts is lower in applied fields compared to basic or fundamental fields both in terms of text and bibliographic coupling-based cosine similarity. For "applied" academics, the expected similarity is 16% and 50% lower when the publication pair consists of one project related and one non-related compared to a publication pairs consisting of non-project-related publications. For academics in non-applied fields, the expected similarity is 4% and 2 % lower when the publication pair consists of one project related and one non-related compared to a publication pairs consisting of non-project-related publications.

Regression table 4

	(1)	(2)	(3)	(4)	(5)	(6)
	full	Applied	Basic	full_bib	Applied_bib	Basic_bib
VARIABLES	cosine	cosine	cosine	cosine	cosine	cosine
II-pair	0.279***	0.358***	0.209***	0.426***	0.487***	0.363***
(0.0151)	(0.0220)	(0.0197)	(0.0267)	(0.0408)	(0.0330)	
IP-pair	-0.117***	-0.173***	-0.0408***	-0.153***	-0.405***	0.0197
(0.00374)	(0.00470)	(0.00562)	(0.0108)	(0.0176)	(0.0133)	
|PY1-PY2|	-0.0281***	-0.0285***	-0.0285***	-0.154***	-0.156***	-0.158***
(0.000167)	(0.000196)	(0.000271)	(0.000856)	(0.00112)	(0.00124)	
Constant	-1.876***	-1.927***	-1.814***	-2.940***	-3.123***	-2.719***
(0.00162)	(0.00197)	(0.00256)	(0.00558)	(0.00734)	(0.00794)	
Academics	115	81	40	114	80	40
Pseudo R2	.03	.03	.02	.12	.11	.12
Observations	746,625	558,689	286,484	659,769	475,962	258,490

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Assessing robustness of results

The issue in this set-up will always be the question of identification of industry-related publications; to what extent we can be sure that publications are related to industry projects and when we can be sure that portfolio publications are not related to projects that are not observed. In table 5, I perform the regressions with a new definition of industry publications. 10 % of publications defined as portfolio publications are co-authored with industry partners. Therefore, the definition used in this study may have a deficit in categorizing publications published prior to the observed project period. As a robustness test, I include all publications co-authored with industry as industry publications. In the regressions, the sign of the coefficients are the same, and the size only moderately different. This indicates that the results are robust in relation to the definition of whether a publication is related to industry or not. The more inclusive way of defining project related publications does not lead to a different interpretation.

Regression table 5

	(1)	(2)	(3)	(4)	(5)	(6)
	full	Applied	Basic oriented	full_bib	Applied_bib	Basic_bib
VARIABLES	cosine	cosine	cosine	cosine	cosine	cosine
II-Pair	0.119***	0.120***	0.123***	0.267***	0.273***	0.220***
(0.00786)	(0.00940)	(0.0134)	(0.0194)	(0.0257)	(0.0277)	
IP-pair	-0.0946***	-0.118***	-0.0714***	-0.210***	-0.295***	-0.147***
(0.00261)	(0.00316)	(0.00420)	(0.00868)	(0.0119)	(0.0118)	
|PY1-PY2|	-0.0282***	-0.0287***	-0.0285***	-0.154***	-0.157***	-0.158***
(0.000167)	(0.000196)	(0.000271)	(0.000854)	(0.00112)	(0.00123)	
Constant	-1.867***	-1.916***	-1.806***	-2.918***	-3.102***	-2.687***
(0.00170)	(0.00208)	(0.00261)	(0.00584)	(0.00784)	(0.00803)	
Academics	115	81	40	114	80	40
Observations	746,625	558,689	286,484	659,769	475,962	258,490
Pseudo R2:	.03	.03	.02	.12	.11	.12

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Discussion

This paper focused on the extent to which academics' research output produced with industry involvement is similar to the research they produce without industry involvement. A comparison between academics' industry and non-industry publications in a sample of 115 engaged academics at the science and technology faculty at Aarhus University shows that collaboration and impact level of journals in which publications are published are similar. Industry publications, however, tend to receive fewer citations than non-industry publications. The difference in citation impact suggests that industry publications may differ in terms of audience, type or content of research, and/or relevance to academic peers.

I examine the extent to which the content or type of university-industry research differs from what the engaged academics otherwise pursue, I analyze the similarity of publications based on abstracts and titles as well as references. I compare the average similarity between academics' industry publications and non-industry publications to the average similarity between non-industry publications. I argue that if the similarity between industry and non-industry publications is equal to the similarity between non-industry publications, then the research with industry is performed on the same range of topics and content as non-industry research. If the average similarity between industry and non-industry publications is lower than the average similarity between non-industry publications, it indicates that industry research is relatively peripheral to the research performed outside of the industry context.

Regression results indicate that academics on average engage in research that is peripheral to what they generally pursue. On average, publications produced as a part of an industry project are 11 % less similar to non-industry publications than non-industry publications are to each other in terms of text used in titles and abstracts and 14 % less similar in terms of referencing. The publications produced in the context of industry projects are relatively more similar to each other than publications produced in non-industry contexts are to each other.

Based on an expectation that the field of science may relate to whether industry-related research resembles academics' other research, I divide the sample into those in traditionally basic disciplines and applied disciplines. Results indicate that academics in applied fields are more likely to engage in peripheral research with industry than academics in basic fields. An important aspect to keep in mind is that the estimated relationship is an average expected relationship. Behind this average relationship is variation of academics that pursue similar research with and without industry and other that pursue very different research in the two contexts. Exploring the factors, in addition to field of science, that may influence which type research strategy an engaged academic pursues is an interesting question to investigate in the future,

Whether 11 and 14 % less in expected cosine similarity is a sizeable difference is difficult to interpret without examining academics' publication portfolios. In the figure below, I present illustrations of two academics' publication portfolios. In figure 1, the portfolio of publications for one academic where the mean cosine similarity between industry and portfolio publications is much lower than the mean cosine similarity between portfolio pairs. And for another in figure 2 where the indicators are the same in both groups. These figures illustrate the two ideal types: one in which academic research with and without industry, according to the indicators, are similar, and one where they are dissimilar.

Using the WoS viewer software, I map the keywords used in the sets of publications. The software places the keywords in relation to each other in a two-dimensional space based on how often they co-occur in documents. Keywords receive a value reflecting how often they occur in industry publications in relation to non-industry publications (normalized by the average proportion of industry publications). This is illustrated by providing a color scheme that reflects the score. From these illustrations it is possible to evaluate whether certain keywords cluster and to what extent certain clusters tend to be disproportionately related to industry publications.

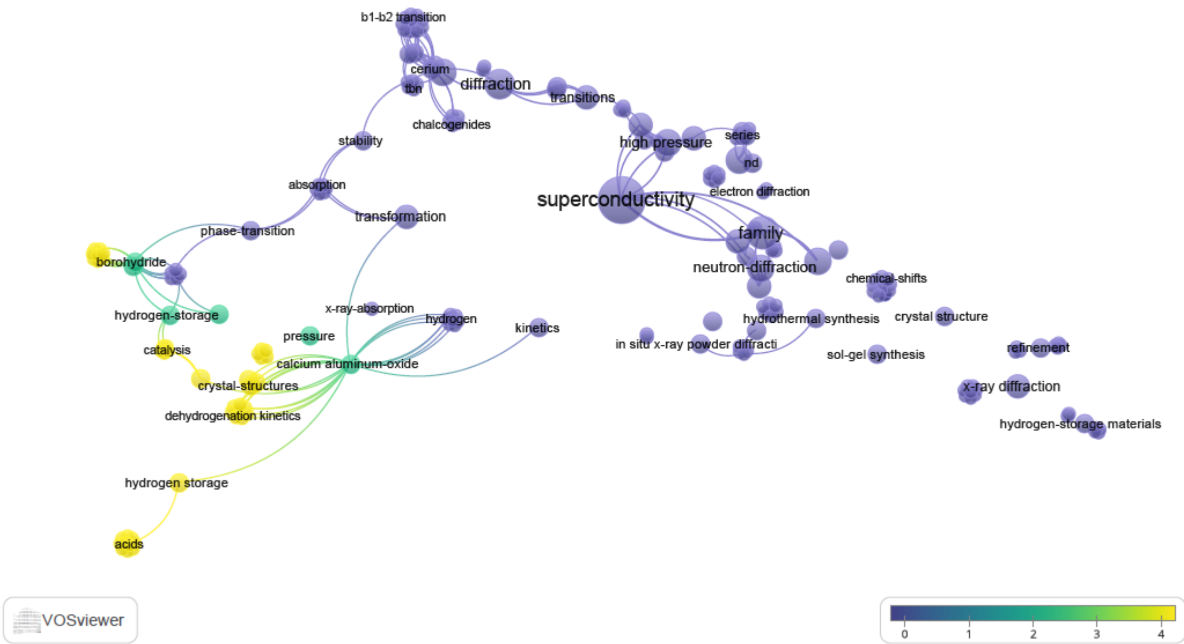
The first example is an associate professor in Chemistry with 46 publications where 5 are industry-related. Indicators show that in terms of text and bibliographic coupling, industry-related publications differ from the remaining portfolio. The average cosine similarity of industry-portfolio pairs is .13 for text and .01 for bibliographic coupling and the average cosine similarity of portfolio pairs is .25 for text and .03 for bibliographic coupling. The difference in cosine similarity between the two groups of publications is – 50 % (text) and - 66 % (bibliographic coupling), which is 4 to 5 times higher than the estimated average expected relationship in the regression. Based on the indicators of similarity, the expectation is that industry publications on average tend to be more peripheral in relation to the remaining portfolio. A cluster of terms appears in which approximately 40 % of the articles that use the terms are industry publications. The other clusters are closely linked to the term *superconductivity* and are only used in non-industry publications. For this academic, it indicates that engagement with industry focuses on relatively peripheral subjects compared to the remaining set of publications. Looking at where the academic published his research, all five industry publications were published in journals that the academic had not published in earlier nor after. This indicates that the research with industry in fact had a different audience and/or a different subject matter.

The second example is an associate professor in engineering with 109 publications, of which 10 are with industry. Indicators show that bibliographic coupling and text is similar in research with and without industry. The average cosine similarity of industry-portfolio pairs is .28 for text and .03 for bibliographic coupling and the average cosine similarity of portfolio pairs is .28 for text and .03 for bibliographic coupling. Based on the indicators of similarity, the expectation is that industry publications on average tend to be as similar to the remaining portfolio as the remaining portfolio publications are to each other. Industry publications share vocabulary and references with portfolio publications to the same degree as portfolio publications share amongst each other.

The keyword network is dense and well connected. In addition, there is a small area of the network that consists mainly keywords that only appear in non-industry publications. However, the majority of terms appear both in industry and non-industry publications. And, no clear cluster of terms appears that occur disproportionately in industry publications. This indicates that the research subjects pursued in both industry and non-industry settings revolve around the same topics. Looking at where the academic published his or her research, nine of ten industry publications are published in journals that the academic had published in earlier, indicating that the research with industry had a similar audience or subject matter.

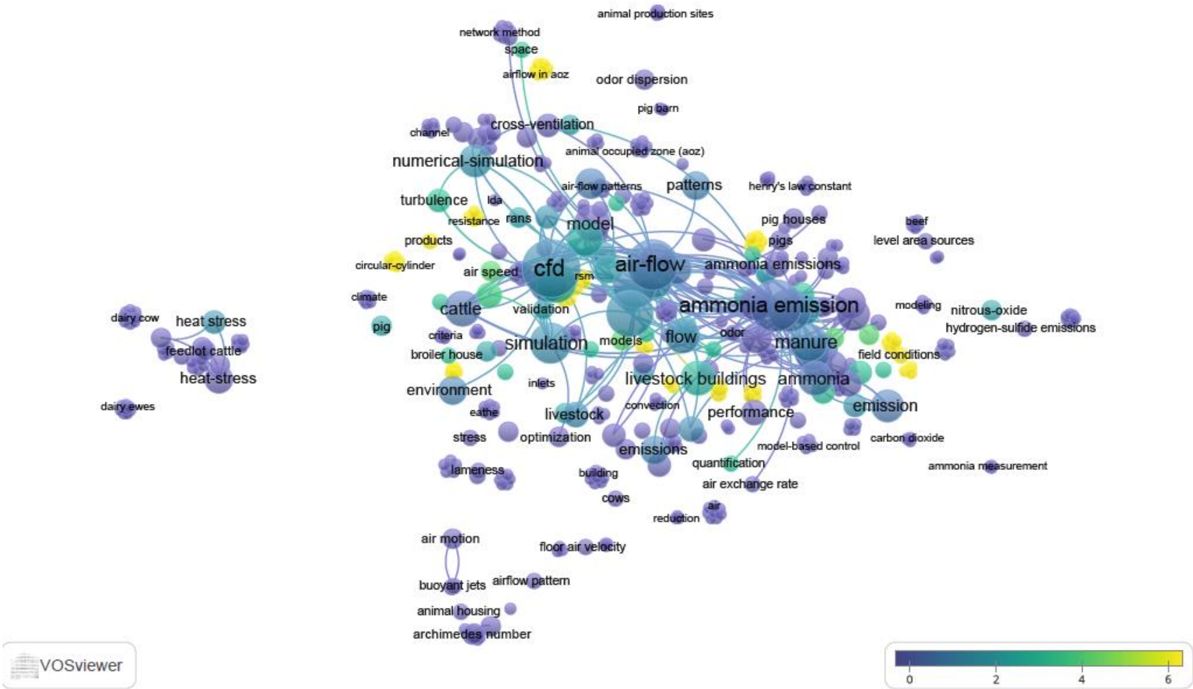
While the figures cannot be translated one-to-one to the regression analyses above, they illustrate how industry research can be relatively central or peripheral to what the academic performs outside the industry context. The patterns in the illustrations and the indicators used in this paper indicate a similar story. From the regression analysis, we would expect on average that academics' publication profiles are most similar to the first figure and that publication profiles of academics in basic sciences to look resemble a mix between the first and second figure and those in applied sciences to look more like the first figure.

Figure 1



All keywords are included. Only strongest 200 links displayed. Interpretation of colour. Normalized frequency of industry publication for a specific key word. 1=proportionate appearance of keyword. 4= appears four times more in industry than expected.

Figure 2



All keywords are included. Only strongest 200 links displayed. Normalized frequency of industry publication for a specific key word. 1=proportionate appearance of keyword. 6= appears four times more in industry than expected.

These two examples serve to illustrate how similarity is measured in this study and to what extent we can identify differences. While I argue that this method is useful in assessing the similarity of research and in uncovering differences between academic and university-industry research, it is equally clear that the method is not able to cover all differences. There are a number of limitations here, for example that text-based similarity is only based on the title and abstract, as opposed to full text. We also lack knowledge on academics' other research, and whether they have been involved in other university-industry projects. However, the robustness analysis shown in table 5 seeks to examine this issue.

It is quite puzzling that it is academics in applied sciences who tend to perform less similar research with industry, while academics in basic sciences tend to perform similar research. It suggests that academics in basic sciences may tend to engage with industry only when it is fits well with their research agenda, while academies in applied sciences are interested in or willing to move their focus in order to investigate other topics and problems either to obtain funding or out of interest. Academics in basic sciences may be motivated primarily by the prospect of funding for their research agenda while academics in applied sciences are more likely to be motivated by the possibility to translate their research into commercial applications.

More research with larger datasets would allow for a more fine-grained division of academics into fields and sub-fields. However, it would require a lot of work to identify industry publications as indicators such as p_industry are neither a precise nor an exhaustive indicator of research outcomes from university-industry collaboration. Additionally, this study only focuses on the most traditional form of research output. Patents, licenses, contributions to trade journals and medical handbooks and protocols are also relevant outputs to assess. Including such outcomes in an analysis would broaden the scope but would potentially complicate and compromise the comparability between research outcomes from the two contexts.

An additional question is to what extent this study can be generalized to academia in general and what is needed to get closer to a good estimate in terms of sample size, method and metrics. The results of the analysis reflect the composition of the sample and therefore the generalizability to a larger population is difficult. The results however, provide a stepping-stone for studies with a larger sample that is more balances and includes a wider set of disciplines and nationalities. This study cannot tease out potential mechanisms nor attempt to track and understand behavior. Instead, the study measures to what extent academics produce different research in the context of UIPs. Qualitative interviews could be helpful in this context, in order to better understand researchers' motivations for pursuing university-industry collaborations, and to what extent this involved changes in the objectives and conduct of their research. One way to further investigate whether research with industry differs from research within the academic system is to simply compare the content of research articles that are funded by or co-authored with industry to research articles co-authored by academics and funded by public agencies. This approach however, is not able however, to answer whether academics pursue similar objectives with and without industry but only how the research which industry participated in differs from academic research.

These are two very different questions of which I only address one. Whether engagement with industry may shift academics research direction in a lasting manner, and to what extent research projects with industry cover similar research what the engaged academics pursue within academia. Academics may temporarily focus on certain subjects and topics that are peripheral to their core focus when engaging in university-industry projects and then return to their core research direction. They may also be pushed, enticed or incentivized to new directions after engaging with industry or by systemic factors such as funding possibilities and industrial influence over research agendas. What Van Looy et al. (2006) investigates is the first question, they look at where academics tend to publish in a period after engaging in inventorship compared to where they published in the period prior (Van Looy et al., 2006).

Similarly, Godin and Gingras (2000) assess whether academics with industrial funding in general tend to choose topics and methodologies based on their commercial potential and not whether this is the case in the single case of an industry project (Godin & Gingras, 2000). This study does not attempt to enter this discussion but instead focuses on the extent to which academics pursue a similar research direction within university-industry projects. For this question, the findings suggest that research with industry tends peripheral relative to the academics other academic research activities. Further research may ask how it is peripheral and whether it creates new avenues of research within the same area and actually affects the academics future research direction. Furthermore, the observation that in this case, there is a difference between the field of science may be investigated further.

References

Aschhoff, B., & Grimpe, C. (2014). Contemporaneous peer effects, career age and the industry involvement of academics in biotechnology. *Research Policy, 43*(2), 367-381. doi:https://doi.org/10.1016/j.respol.2013.11.002

Behrens, T. R., & Gray, D. O. (2001). Unintended consequences of cooperative research: impact of industry sponsorship on climate for academic freedom and other graduate student outcome. *Research Policy, 30*(2), 179-199. doi:10.1016/s0048-7333(99)00112-2

Bekkers, R., & Freitas, I. M. B. (2008). Analysing knowledge transfer channels between universities and industry: To what degree do sectors also matter? *Research Policy, 37*(10), 1837-1853. doi:10.1016/j.respol.2008.07.007

Bikard, M., Vakili, K., & Teodoridis, F. (2019). When Collaboration Bridges Institutions: The Impact of University–Industry Collaboration on Academic Productivity. *Organization Science, 30*(2), 426-445. doi:10.1287/orsc.2018.1235

Bloch, C., Ryan, T. K., & Andersen, J. P. (2019). Public-private collaboration and scientific impact: An analysis based on Danish publication data for 1995-2013. *Journal of Informetrics, 13*(2), 593-604. doi:10.1016/j.joi.2019.03.003

Blumenthal, D., Campbell, E. G., Causino, N., & Louis, K. S. (1996). Participation of life-science faculty in research relationships with industry. *New England Journal of Medicine, 335*(23), 1734-1739. doi:10.1056/nejm199612053352305

Bozeman, B., Fay, D., & Slade, C. P. (2013). Research collaboration in universities and academic entrepreneurship: the-state-of-the-art. *Journal of Technology Transfer, 38*(1), 1-67. doi:10.1007/s10961-012-9281-8

Caron, E., & van Eck, N. J. (2014). *Large scale author name disambiguation using rule-based scoring and clustering*. Paper presented at the Proceedings of the 19th international conference on science and technology indicators.

D'Este, P., & Perkmann, M. (2011). Why do academics engage with industry? The entrepreneurial university and individual motivations. *Journal of Technology Transfer, 36*(3), 316-339. doi:10.1007/s10961-010-9153-z

Dillon, M. (1983). Introduction to modern information retrieval: G. Salton and M. McGill. McGraw-Hill, New York (1983). xv+ 448 pp., $32.95 ISBN 0-07-054484-0. In: Pergamon.

Dutrenit, G., De Fuentes, C., & Torres, A. (2010). Channels of interaction between public research organisations and industry and their benefits: evidence from Mexico. *Science and Public Policy, 37*(7), 513-526. doi:10.3152/030234210x512025

Florida, R., & Cohen, W. (1999). Engine or infrastructure? The university role in economic development. *From industrializing knowledge. University–industry linkages in Japan and the United States*, 589-610.

Godin, B., & Gingras, Y. (2000). Impact of collaborative research on academic science. *Science and Public Policy, 27*(1), 65-73. doi:10.3152/147154300781782147

Goldfarb, B. (2008). The effect of government contracting on academic research: Does the source of funding affect scientific output? *Research Policy, 37*(1), 41-58. doi:10.1016/j.respol.2007.07.011

Gulbrandsen, M., & Smeby, J. C. (2005). Industry funding and university professors' research performance. *Research Policy, 34*(6), 932-950. doi:10.1016/j.respol.2005.05.004

Hottenrott, H., & Thorwarth, S. (2011). Industry Funding of University Research and Scientific Productivity. *Kyklos, 64*(4), 534-555. doi:10.1111/j.1467-6435.2011.00519.x

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy, 26*(1), 1-18. doi:https://doi.org/10.1016/S0048-7333(96)00917-1

Kessler, M. M. (1963). BIBLIOGRAPHIC COUPLING BETWEEN SCIENTIFIC PAPERS. *American Documentation, 14*(1), 10-&. doi:10.1002/asi.5090140103

Larivière, V., & Sugimoto, C. R. (2019). The Journal Impact Factor: A Brief History, Critique, and Discussion of Adverse Effects. In W. Glänzel, H. F. Moed, U. Schmoch, & M. Thelwall (Eds.), *Springer Handbook of Science and Technology Indicators* (pp. 3-24). Cham: Springer International Publishing.

Lebeau, L. M., Laframboise, M. C., Lariviere, V., & Gingras, Y. (2008). The effect of university-industry collaboration on the scientific impact of publications: the Canadian case, 1980-2005. *Research Evaluation, 17*(3), 227-232. doi:10.3152/095820208x331685

Lee, Y. S. (2000). The sustainability of university-industry research collaboration: An empirical assessment. *Journal of Technology Transfer, 25*(2), 111-133.

Lin, M. W., & Bozeman, B. (2006). Researchers' industry experience and productivity in university-industry research centers: A "scientific and technical human capital" explanation. *Journal of Technology Transfer, 31*(2), 269-290. doi:10.1007/s10961-005-6111-2

Martyn, J. (1964). BIBLIOGRAPHIC COUPLING. *Journal of Documentation, 20*(4), 236-236. doi:10.1108/eb026352

Motta, V. (2019). Estimating Poisson pseudo-maximum-likelihood rather than log-linear model of a log-transformed dependent variable. *RAUSP Management Journal, 54*(4), 508-518. doi:10.1108/RAUSP-05-2019-0110

Perkmann, M., Salandra, R., Tartari, V., McKelvey, M., & Hughes, A. (2021). Academic engagement: A review of the literature 2011-2019. *Research Policy, 50*(1), 104114. doi:https://doi.org/10.1016/j.respol.2020.104114

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Brostrom, A., D'Este, P., . . . Sobrero, M. (2013). Academic engagement and commercialisation: A review of the literature on university-industry relations. *Research Policy, 42*(2), 423-442. doi:10.1016/j.respol.2012.09.007

Perkmann, M., & Walsh, K. (2007). University-industry relationships and open innovation: Towards a research agenda. *International Journal of Management Reviews, 9*(4), 259-280. doi:10.1111/j.1468-2370.2007.00225.x

Slaughter, S., & Leslie, L. L. (2001). Expanding and Elaborating the Concept of Academic Capitalism. *Organization, 8*(2), 154-161. doi:10.1177/1350508401082003

Tartari, V., & Breschi, S. (2012). Set them free: scientists' evaluations of the benefits and costs of university-industry research collaboration. *Industrial and Corporate Change, 21*(5), 1117-1147. doi:10.1093/icc/dts004

Van Looy, B., Callaert, J., & Debackere, K. (2006). Publication and patent behavior of academic researchers: Conflicting, reinforcing or merely co-existing? *Research Policy, 35*(4), 596-608. doi:https://doi.org/10.1016/j.respol.2006.02.003

Vladutz, G., & Cook, J. (1984). BIBLIOGRAPHIC COUPLING AND SUBJECT RELATEDNESS. *Proceedings of the American Society for Information Science, 21*, 204-207.

Waltman, L., Calero-Medina, C., Kosten, J., Noyons, E. C. M., Tijssen, R. J. W., van Eck, N. J., . . . Wouters, P. (2012). The Leiden ranking 2011/2012: Data collection, indicators, and interpretation. *Journal of the American Society for Information Science and Technology, 63*(12), 2419-2432. doi:https://doi.org/10.1002/asi.22708

Chapter 7:
Public-private collaboration and scientific impact: An analysis based on Danish publication data for 1995–2013

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Regular article

Public-private collaboration and scientific impact: An analysis based on Danish publication data for 1995–2013☆

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A B S T R A C T

In the past few decades, there has been increasing interest in public-private collaboration, which has motivated lengthy discussion of the implications of collaboration in general, and co-authorship in particular, for the scientific impact of research. However, despite this strong interest in the topic, there is little systematic knowledge on the relation between public-private collaboration and citation impact. This paper examines the citation impact of papers involving public-private collaboration in comparison with academic research papers. We examine the role of a variety of factors, such as international collaboration, the number of co-authors, academic disciplines, and whether the research is mainly basic or applied. We first examine citation impact for a comprehensive dataset covering all Web of Science journal articles with at least one Danish author in the period 1995–2013. Thereafter, we examine whether citation impact for individual researchers differs when collaborating with industry compared to work only involving academic researchers, by looking at a fixed group of researchers that have both engaged in public-private collaborations and university-only publications. For national collaboration papers, we find no significant difference in citation impact for public-only and public-private collaborations. For international collaboration, we observe much higher citation impact for papers involving public-private collaboration.

1. Introduction

This paper examines the relation between public-private co-authorship and the scientific impact of publications. In the past few decades, there has been increasing in the role of public-private collaboration for research and innovation. This includes both formal collaboration and interactions of a more informal nature (Perkmann et al., 2013). Parallel to this has been strong increases in the number policies to promote public-private collaboration, both in terms of research policy that promotes the so-called third mission activities of universities, commercialization and entrepreneurialism in general, and in terms of innovation policy that encourages companies to engage in interaction with public research.

Public-private research collaboration can be seen both from the perspective of universities and from that of business.[1] Research has shown that academic researchers' motivations to collaborate with business may vary greatly, from a more

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[1] For a comprehensive review of the literature on research collaboration, see Bozeman et al. (2013).

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'entrepreneurial logic' that focuses on technology development and commercialization, to a more 'academic logic' that reflects many of the traditional values of the scientific system (D'Este & Perkmann, 2011).

Research collaboration may have a number of potential benefits, such as division of labor, knowledge transfer and combinations of different perspectives, network access and greater visibility, but organizing and engaging in collaboration may encounter increased costs in time and financial resources (Katz & Martin, 1997). Among the potential benefits for public-private collaboration in particular are a greater utilization of academic research in business innovation, knowledge transfer and exchange, mutual learning, and a greater alignment of academic and business research. The latter can be seen in a positive light as a 'hybrid system' (Owen-Smith, 2003) in which there are important feedbacks and synergies between academic and entrepreneurial research. However, this entrepreneurial influence on academic research agendas has also been highlighted as an important danger of the entrepreneurial university. A main concern here is that a shift in focus towards bridging academic and entrepreneurial research will detract from focus towards the type of 'blue-skies' research that often lies behind significant scientific breakthroughs (Etzkowitz, 2003). This motivates the concern that an overly short-term focus on reaping the benefits of research now may ultimately result in a slowing of the growth of scientific knowledge. Connected to this are a number of other potential, negative implications, such as an excessive shift from fundamental to applied research, less academic freedom (Behrens & Gray, 2001), manipulation of science for short term gain (Slaughter & Leslie, 1997) and restrictions on the diffusion of open knowledge.

However, differences between purely academic and public-private collaboration are not always clear. Perkmann and Walsh (2009) find in their qualitative study of university-industry collaboration in the engineering sciences that research far from application is more likely to be published while research close to application is more likely to be irrelevant for the scientific community or suffer from secrecy concerns. Therefore, we would expect that co-authored papers with industry are often a result of what they call knowledge generation projects. This suggests that co-authored papers may often be a result of traditional research projects, and thus, with impact similar to that of other co-authored papers.

Both research collaboration in general and public-private collaboration in particular have been the study of a wide range of literature, approaching the topic from a number of angles. Bozeman, Fay, and Slade (2013) review the topic of research collaboration from the perspective of the individual university researcher, with focus on aspects such as the attributes of collaborators, collaborative process and organization characteristics as the affect collaboration choices and outcomes. Perkmann et al. (2013) review the literature that focuses on public-private collaborations themselves, and the various forms of academic engagement in these interactions.

Our focus in this paper is more specifically on collaboration in the form of co-authorships and the relation between public-private co-authorship and scientific impact. Co-authorship has long been advocated and used as a measure of research collaboration, though at the same time recognizing its limitations (Katz & Martin, 1997). Its advantages include verifiability, data availability, ease of measurement, and quantifiability that allows analysis that would not be possible with more qualitative forms of data. However, it can at best be considered as only a partial measure of research collaboration. Co-authorship can both be viewed as one of many different forms of output of collaboration, and at the same time as a diffuse measure, where we do not know the nature and intensity of interaction of individual co-authors behind papers. These limitations notwithstanding, there is still substantial interest in different forms of co-authorship and their relation to scientific impact. Analysis of this relation can both inform issues concerning the importance of collaboration and contribute to better understanding of the relation between collaboration and citation impact, which is particularly important given the widespread use of bibliometric and citation based indicators.

There is now widespread evidence that co-authored papers are on average more highly cited than papers with a single author, and that papers involving international collaboration are even more highly cited (Glänzel & Schubert, 2001; Persson, Glänzel, & Danell, 2004; Sørensen & Schneider, 2017; Van Raan, 1998). However, there is much less evidence on the citation impact for public-private collaboration in particular. Historically, research collaboration has increasingly become the norm in research, with the difference in citation frequency between multiple and single author papers increasing over time (Wuchty, Jones, & Uzzi, 2007). However, at the same time, the marginal effect of increases in the number of authors appears to be diminishing (Larivière, Gingras, Sugimoto, & Tsou, 2015).

Godin and Gingras (2000) find for Canada that journal factor impact for intersectoral collaboration research is on average not lower than for university research collaboration. However, it is unclear whether a similar result holds for the citation impact of papers. Katz and Hicks (1997) find for the UK that the number of citations per paper are increasing in the number of co-authors, number of collaborating institutions, foreign collaboration, and industry collaboration. However, this early study was not able to analyse or control for field differences. Liu, Chang, and Chen (2012) find for Taiwan that in general, international collaborations have higher citation impacts than domestic collaborations.

Lebeau, Laframboise, Larivière, and Gingras (2008) examine this using data for Canada for the period 1980–2005 and find that while public-private collaborations are on average published in lower impact journals, they receive on average higher (field normalized) citation counts than for university only or industry only papers. However, they do not control for confounding variables, such as number of authors and whether the co-authors are from Canada or abroad. The, comparison thus, stays at a descriptive level, where it is difficult to discern to what extent the higher impact is related to a higher number of authors, the internationality of the paper or the fact that industrial actors have been involved.

This paper examines the citation impact of papers involving public-private collaboration in comparison with academic research papers. We ask whether publications with industrial co-authors have different expected impact than publications with only public research organizations – thus, we ask whether there is an added academic value to industrial collaboration.

In comparing public research with public-private collaboration, it is unclear whether we are comparing the same types of articles, for example concerning the nature of the research and the ability of researchers involved. In other words, there are a number of factors that complicate making a valid comparison. In this paper, we will seek to control for a variety of these factors. In particular, we examine the role of the number of co-authors, academic disciplines, and whether the research is mainly basic or applied. The analysis in this paper draws on the project Collaboration in Research (see eg. Bloch, Ryan & Andersen, 2016; Bloch, Andersen, Ryan & Schneider, 2017).

It has been shown that citation impact is positively associated with the number of co-authors, hence differences in the average number of co-authors for different forms of collaboration can influence comparisons. One extreme example is to what degree extremely large consortiums of co-authors, such as those within high-energy physics, influence comparisons, or whether there are large differences in the distribution of disciplines across types of collaboration. Self-citations can be removed, though self-citation may in turn have an amplifying effect by creating more visibility of research and thereby more potential (non-self) citers (Van Raan, 1998).

A key factor that has received much attention is controlling for differences in citation behavior across fields (Waltman, 2016). Field-normalised measures of citation impact control for these differences to a large degree, but may not fully be able to account for differences in citation behavior among applied vs. more fundamental research within specific disciplines. The latter basic-applied distinction is particularly difficult to classify systematically, and we will rely on a rough proxy based on the journal for the publication and on the set of journals cited by each paper within the medical sciences that attempts to distinguish between clinical research and basic biomedical research. The method uses journals to classify articles into one of ten different fields (NordForsk, 2014). More advanced methods exist that classify individual articles based on text analysis (Weber, 2013; Boyack et al., 2014). However, given that this is only one of many factors that we examine here, these extensive methods were viewed to be outside the scope of the work in this paper.

An additional dimension that we examine is international collaborations in comparison with national collaboration. These two dimensions, public-private and national-international, are used to create a classification of collaborations types.

Finally, we examine whether citation impact for individual researchers differs when collaborating with industry compared to work only involving academic researchers, by looking at a fixed group of researchers that have both engaged in public-private collaborations and university-only publications. This methodology reduces the potential bias of high performing researchers selecting into public-private collaborations more often than low performing researchers do.

The analysis is conducted based on publications in Web of Science with at least one Danish address over the period 1995–2013. The analysis covers a dataset of 183,812 journal articles. We identified academic and industrial authors using a combination of algorithms and manual coding (these are described below). In order to control for the above factors in our comparison, three sets of analyses are conducted: a descriptive analysis of mean normalized citation scores (MNCS) across different forms of collaborations; a multivariate regression analysis of the role of these factors for normalized citation scores; and a comparison of citation impact for different forms of collaboration for a fixed set of researchers that have engaged in each type of collaboration.

2. Method and data

We examine both whether collaborations are among companies and public research (public-private collaborations) and whether collaborations are national or international. We utilize the following classification consisting of five mutually exclusive publication types:

Type 1: National public research

Danish public research organization (university or government research institute; no industry);

Type 2: International public research

Danish and international public research organizations (no industry)

Type 3: National public-private research

Collaborations between Danish public research organizations and Danish companies (no international partners);

Type 4: International public-private research

International public-private collaborations - public-private collaborations with at least one international partner[2]

Type 5: Industrial research

Industry only (Danish companies, potentially also including foreign companies)

The relationship between the five types is illustrated in Table 1. We use this categorization to distinguish between different types of publications in relation to the national-international and public-private distinction. We analyze in two parts whether the citation impact of papers differ depending on the type. The first part analysis examines this at a macro level while the second part examines this on a micro level.

In addition to this, other classifications are used to prepare and analyze the data. This includes the 254 Web of Science field categories, which are used for the field normalization of citation-based measures, and a broader categorization of fields (NordForsk, 2014) for use in the regression analysis.

[2] Type 4 includes both collaborations between international companies and domestic public researchers as well as international public researchers and domestic companies.

Table 1
Overview of collaboration types by organization type and internationality. Public research organizations are shortened as PRO.

	PRO (Only)	Industry & PRO	Industry (Only)
National	Type 1	Type 3	
International	Type 2	Type 4	Type 5

2.1. Measuring citation impact

We use data from CWTS' in-house version of Clarivate Analytic's Web of Science citation indices (CI-WoS). The CWTS in-house version of the WoS database indicates whether individual publications include an author from private industry and whether the publication is an international collaboration involving authors from two or more countries. In general, a fixed three-year citation window was used to calculate citation impact. However, for the multivariate regression analysis, a variable length window of three or more years was used to reduce the number of articles with no citations (this point is discussed in greater detail below).

We have enhanced this data by manually validating and classifying all Danish addresses (public research institution, private business or other public organisation). A rule-based algorithm was used to identify universities, other public research institutions and private businesses. Affiliations were examined to determine if they contained text that identified their type (for example "university" in the name, or "Inc.", "Ltd.", or "AS"). All remaining organisations with Danish addresses were manually coded into four categories: public sector research organization or other public sector organization,[3] private business, and unknown. We considered privately owned companies as private businesses, with the exception of national research institutes, which can be privately owned, but are also affiliated to a government institution. Also consultancies were included in the definition of private businesses, but individuals were categorized as "other". In all, 6133 Danish organization names were coded manually and compared to the Danish Central Business Register. Unknown names were disregarded in the categorization of collaboration types for articles, and the article itself was removed from the analysis if institution type could not be identified for any of the co-authors. The involvement of foreign businesses was validated using CWTS indicators of industry co-authorship.

The analysis relies in particular on the mean normalized citation score (MNCS). The MNCS indicator is obtained by averaging the normalized citation scores (NCS) of all publications of a unit or grouping. If a unit has an MNCS indicator of one, the publications of the unit have been cited on par with world averages (or more precisely, database averages) for similar publications in terms of field and publication year. An MNCS indicator of, for instance, two means that on average the publications of a unit have been cited twice as frequently as the world average of that field, the same year as the paper is published (Waltman et al., 2012). Average field citation rates depend heavily on the field classification used. Although parts of the analysis presented in this paper uses a very broad categorization of just ten fields, grouping Web of Science journal categories together, we use the individual journal categories for the normalization. While the article-specific classification by Waltman and Van Eck (2013) would have allowed a more granular and exact normalization of the individual item (Lundberg, 2007) than journal-based categorizations, the existing classification does not cover publications prior to 2000.

There may be cases where single collaborations involving a very large number of authors strongly influence MNCS for the individual author. A method to reduce the influence of single papers involving extremely large collaborations is to fractionalize citation scores by the number of authors. Hence, we utilize both full and fractional counts of the MNCS indicator (Waltman & van Eck, 2015):

$$Full\quad count\quad MNCS = \frac{\sum NCS_i}{p};\quad Fractional\quad count\quad MNCS = \frac{\sum \frac{NCS_i}{n_i}}{\sum \frac{1}{n_i}}$$

where NCS_i is normalized citation score for paper i, p is number papers, and n is number authors for paper i.[4]

Citation data is typically highly skewed, with a large number of articles with a small number of citations and a small number with a very high number of citations. For this reason, it is important that averages are calculated for large groups of papers, minimizing the sensitivity to extreme outliers. To improve the robustness of results, instead of calculating citation based indicators for each individual year, we have constructed indicators for four time periods of 4 to 5 years, ie. from 1995 to 1999, 2000–2004, 2005–2009 and 2010–2013.

3. Descriptive statistics

For the period 1995–2013, there are in total 189,703 journal articles in the WoS database that have at least one Danish address. Fig. 1 shows developments in Danish journal articles over time, from 1995 to 2013, classified into five broad

[3] Other public sector organisations were initially coded separately, but this group did not prove large enough to be analysed on its own, and in many cases was difficult to distinguish from public sector research organisations. Based on this, the two groups were combined.

[4] An example: suppose there is one paper with one author and NCS=1 and one paper with three authors and NCS=2. Full count MNCS for these two papers is 1.5 and fractional count MNCS is 1.25.

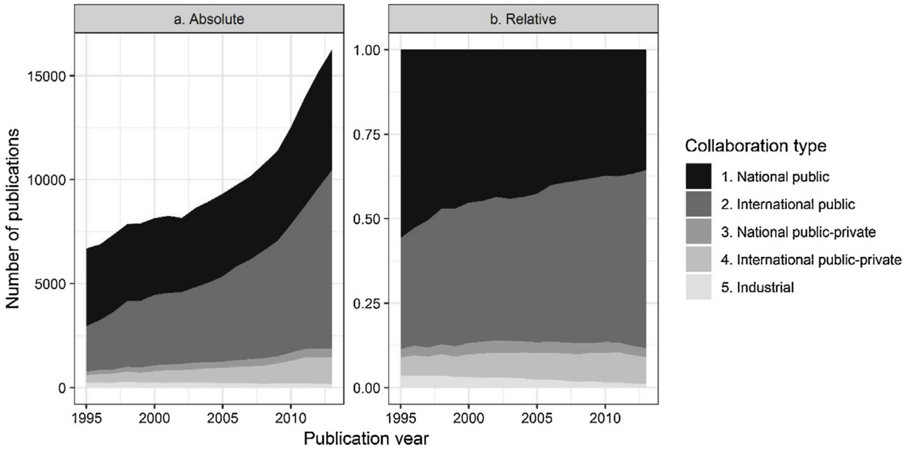

Fig. 1. Distribution of collaboration types over time for Danish research, 1995–2013. Danish public research only and industry only also include solo articles with no co-authors. Public-private collaboration includes both Danish and international collaborations.

categories, National public research, international public research, national public private research, international public-private research and industrial research.

The total annual number of Danish journal articles in WoS has increased dramatically from 6738 in 1995 to 16,351 in 2013. Growth has been particularly strong in the last 10 years, where the total number of articles has increased by 87%. The far majority of publications are public research papers. In particular, international public research has increased almost four-fold over the period and now accounts for over half of all publications. The share of journal articles involving public-private collaboration increased from 7.8% in 1995 to 11.9% in 2010. Since 2010, the share has fallen slightly, with the share at 10.5% in 2013. In all, the share of total publications involving some form of international collaboration (including both pure public and public-private collaborations) has increased from 39% in 1995 to 61% in 2013. Among public-private collaborations, the share of papers involving international collaboration has also risen, from 68% to 75% over the same period.

National public research and Industrial research include papers with single authors. In both cases, the share of solo papers has declined greatly over time. The share of National public research papers with single authors has declined over the period from 26% in 1995 to 15% in 2013, while the share of industrial research papers with a single author has fallen from 36% (68 out of 187) in 1995 to 18% (15 out of 84) in 2013.

It should also be noted that there has been strong growth in the global, total number of journal articles in the WoS database, which can likely explain part of the development in the articles and collaboration. In the period from 1995 to 2013, the total annual number of articles has increased by 113% (based on own calculations) in comparison to 143% in our sample covering Danish authors. The growth in WoS is driven by two factors: strong global increases in research publication activity, particularly in Asia but also in Denmark and other western countries; and increases in the number of journals included in the database (in particular in 2006, where a large number of additional journals were included in the WoS database). The latter has large importance for many Asian countries, but is less important in relative terms for countries like Denmark, whose primary publication channels are already included in WoS.

However, it is clear that this growth in journal coverage has had some degree of influence on the overall growth of journal articles (with a Danish address) in WoS. On the other hand, it should be expected that increases in publication activity lead to an expansion in the number of journals used, since most journals have a fixed number of articles that they can publish each year (though minor increases are possible through increases in the annual number of issues). The increase in data coverage in the databases does not seem to exceed the development in collaboration.

Fig. 2 shows MNCS for different forms of collaboration involving Danish public research. As mentioned above, these indicators are normalized both across fields and according to global (database) averages. Overall, citation impact for Danish research is high in international comparison, with Denmark ranking among the top five countries in average citation impact (Danish Ministry of Higher Education & Science, 2018). As the figure shows, MNCS for all articles with at least one Danish public research co-author was 1.3 in 1995–1999 and has gradually increased over time, reaching 1.5 in 2010–2013. This same upwards trend can be found in many of the other top performing countries.

Generally speaking, and among papers involving Danish public research, MNCS is lowest for papers only involving Danish public research. Taking the entire period into account, national public-private collaborations have typically had a slightly higher MNCS, though the difference is not large and in fact MNCS for Danish public research papers is slightly higher in 2010–2013, 1.2 compared to 1.1.

When examining these figures, it is important to take into account overall developments in research production, where there is a growing shift towards international collaboration. It may very well be the case that many research projects and papers that would have been conducted nationally 15–20 years ago are now performed with the involvement of international partners. And, it may also be the case that these papers tend to be above average in terms of performance.

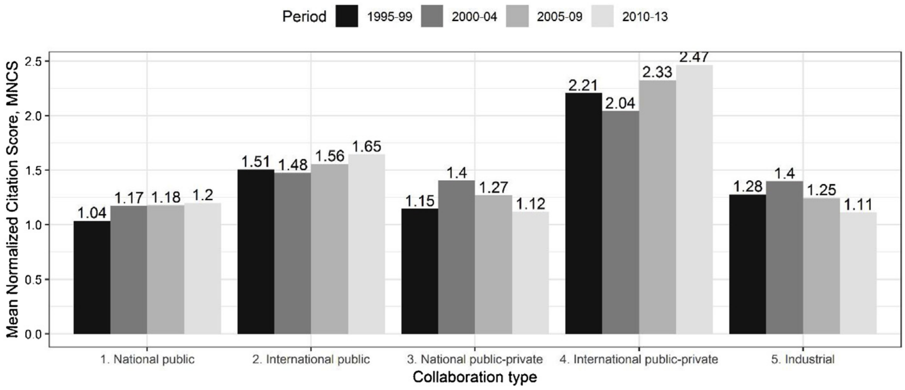

Fig. 2. Mean Normalized Citation Score (MNCS) for different types of collaboration, 1995–2013. Based on publications with at least one Danish address.

Moving along, MNCS for international collaborations only involving public research is higher than national collaborations, at around 1.5 for much of the period and 1.6 in 2010–2013. Hence, in this last period, (field-normalised) citation impact is around 40% higher for these international public collaborations than for national collaborations.

As Fig. 2 clearly shows, by far the highest citation impact is found for international, public-private collaborations involving multiple partners. In the figure below, we show impact for all international multi-partner collaborations that include industry. Over the period, MNCS ranges from 2.2 to 2.5 in the last period. The latter implies citation impact that is 247% higher than world averages. These results thus also show that international papers involving public-private collaboration have on average substantially higher impact than international collaborations only involving public research organisations. This raises a number of further questions. For example: Are the topics or types of research that these papers cover different, having a greater importance and attracting greater attention? Do they more often involve top researchers? Is there something about the synergies of the collaboration that produces higher impact papers? Are the results driven by a small group of very influential papers involving an extremely large number of co-authors? The remainder of this paper, attempts to qualify the discussion through both a macro and micro level analysis of impact and collaboration.

4. Article level regression analysis

In the regression below, we analyze the relationship between the public-private as well as national-international with citation impact. Highly skewed citation distributions are problematic for OLS regression, and Thelwall & Wilson (Thelwall & Wilson, 2014) suggest using the logarithm of citations plus one (to allow inclusion of uncited publications), as this is shown to give consistent estimates. We would argue that this method fits even better for normalized citation data because normalized citations tend to follow a continuous lognormal distribution. In the descriptive analysis above, where we also examine developments over time, citation scores were calculated using a fixed three year window. In contrast, we have chosen here to allow citation windows to vary according to the number of years available, while at the same time using year dummies to account for differences in average citation impact over years. Our main reason behind this choice is to reduce the number of papers with zero citations and at the same time increase the scope of citation activity that the regression analysis examines. Hence, the dependent variable in the regressions is the log of (NCS + 1).

As described in the methods, field-normalization is based on a finely granulated article-level classification system. However, we summarise results here in 10 fields based on the 257 subject classes used by Clarivate Analytics: Biology, Chemistry, Health Sciences, Biomedicine, Engineering & Materials Sciences, Physics & Mathematics, Agriculture, Fisheries & Forestry, Geosciences, Social Sciences & Humanities, and Multidisciplinary, derived from NordForsk (2014). Field dummies are created based on these categories. We also conduct the regressions for individual fields to examine potential field differences in the relation between citation impact and types of collaboration. Finally, within the medical sciences, the constructed fields provide a rough distinction between clinical research (Health Sciences) and basic research (Biomedicine).

The number of authors is generally known to be highly related to the number of citations a publication receives. Also after removing self-citations. The reason can be that there are benefits to being many authors, that the number of authors correlates with other variables that affect impact and the self-citations have an increasing effect – i.e. two self-citations lead to more than double the amount of self-citations that do one self-citation. Simply removing self-citations does not control for the marketing effect of self-citations. And to allow for a possible non-linear relationship between the number of authors and citation impact, we also include the square of the number of authors in regressions.

We control for the number of authors, year of publication and field. Regressions 2–6 are on the level of fields. The regressions mirror the descriptive statistics above, however, the differences are smaller, when we control for number of authors.

The main explanatory variables in the analysis are for types of collaboration. Dummy variables have been created for:

Table 2
Distribution of publications across fields (above horizontal rule), MNCS, number of authors (n_authors) and number of publications (n_pub) for different collaboration types.1995–2013.

	Total	National public	Inter-national public	National public-private	Inter-national public-private	Industrial
Chemistry	0.09	0.08	0.08	0.14	0.10	0.09
Health sciences	0.37	0.40	0.33	0.24	0.38	0.22
Biomedicine	0.23	0.21	0.24	0.33	0.34	0.14
Engineering & materials	0.12	0.12	0.10	0.22	0.13	0.27
Physics & mathematics	0.15	0.12	0.19	0.09	0.10	0.15
Agriculture, fisheries & forestry	0.11	0.12	0.10	0.19	0.10	0.26
Geosciences	0.05	0.04	0.06	0.03	0.03	0.07
Multidisciplinary	0.02	0.01	0.03	0.01	0.02	0.01
Social sciences	0.05	0.06	0.03	0.01	0.00	0.04
MNCS	1.42	1.18	1.71	1.25	2.13	1.24
n_authors	11.24	3.67	16.75	5.03	71.04	4.19
n_pub	183812	99865	69979	6836	6936	196

- Whether at least one author is from a Danish private business (dk_indu)
- Whether at least one author is from a foreign private business (int_indu)
- Whether at least one author is from a foreign university (int_univ)
- Whether there is both at least one author from a foreign private business and one author from a foreign university (intl_indu_uni)

These dummy variables are not mutually exclusive and allow us to compare the citation impact of different forms of collaboration, while at the same time controlling for other factors. These dummies are also used to construct the list of types of collaborations defined in Section 2.

Hence, the explanatory variables included in the regressions are: number of authors, number of authors squared, dummies for collaboration types, field dummies and year dummies. The regressions are first conducted for all fields and thereafter for each individual field that accounts for at least 10% of total articles.

Table 2 shows descriptive statistics for the dataset. For each type of collaboration, the table shows the distribution of articles across fields, MNCS, the average number authors per paper, and total number of publications. As noted above, the number of pure industry papers is extremely low and has been declining over the period from 1995 to 2013. Hence, the far majority of papers co-authored by industry are done in collaboration with public research. There are about 7000 papers each with (only) national public-private collaboration and with international public-private collaboration. As expected, the average number of authors per paper is higher for international collaborations, particularly for international public-private collaborations. The distribution of articles across fields varies according to type of collaboration. Health sciences has the highest share of publications in total (37%) and has its highest shares in national public and international public-private collaborations. Shares are highest for biomedicine in national and international public-private collaborations. Engineering & materials has highest share among national public-private, while physics & math is highest within international public.

4.1. Regression results

The results of the regressions are shown in Supplementary Table S1 reports coefficient estimates for the OLS regression on log(NCS + 1) as well as 95% confidence intervals. Fig. 3 shows the estimated factor effects of the main variables. Coefficients from the main regression are transformed to be interpreted as factor effects on NCS + 1 and include 95% confidence intervals. Thus, int_univ is 1.216 in Fig. 3 (0.189 in regression) it means that if an article is authored by an international author the expected NCS + 1 of that article increases by a factor of 1.216 or by 21.6%.[5] In Fig. 3, results are shown for the full sample covering all fields, and individually for each field with over 10% of observations. In the following sections, we report the regression coefficients as well as the transformed percentage effects on ncs+1.

A result that holds both in total and for individual fields is that citation impact is increasing in the number of authors but that this relation diminishes as the number of authors grows (ie. decreasing in authors squared). These results thus correspond well with earlier studies (e.g. Larivière et al., 2015; Wuchty et al., 2007). However, coefficient size is very small for the number of authors and its square (sq_authors), as can be seen from Fig. 3.

4.1.1. Domestic-international dimension

The regression results indicate that international collaboration with university researchers outside Denmark is associated with a higher expected impact. If a research publication with a Danish author has an author from a university outside Denmark, the expected impact (NCS + 1) is approximately 21.6% higher than an article without international authors. This

[5] The change in NCS+1 given a change from 0 to 1 in int_univ is 21,6%=100*[exp(0.196*1)-1]

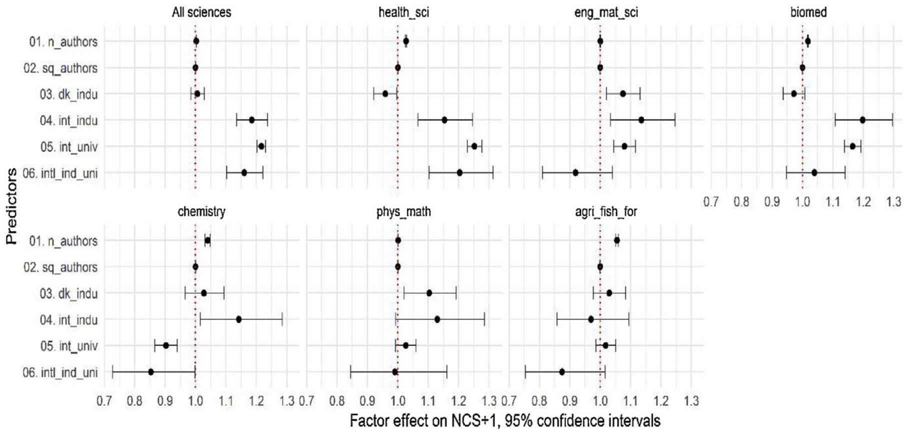

Fig. 3. The main predictors for (NCS + 1) as estimated factor effects. Transformed from regression by taking the exponential of estimated coefficients on log(NCS + 1) in OLS regressions. Results are divided into seven models containing all sciences and the six most prominent research areas. Supplementary Table S1 See for estimated coefficients.

reiterates the many empirical studies that have found that international collaborations tend to have a higher impact than domestic collaborations (e.g. Glänzel & Schubert, 2001; Sørensen & Schneider, 2017; Van Raan, 1998).

Whether this relationship relates to impactful researchers collaborating more with international colleagues and/or to international collaborations in and of themselves giving rise to extra benefits is not apparent in this regression.

This finding is consistent among all fields except chemistry where surprisingly there seems to be a negative relationship. This result within chemistry is somewhat puzzling, but it appears to at least be partially driven by higher impact among the top 1% for national papers compared to papers co-authored with international researchers. If we for example remove papers with NCS greater than 5 (0.6% of publications within chemistry) then the coefficient for international public research is still negative but is reduced by half and is insignificant. Additionally, the relationship is quite weak in Physics and mathematics – which may relate to the fact that most publications within physics are international collaborations.

4.1.2. Public-private dimension

The regression indicated that overall, collaboration with international industrial authors as well as international university authors is associated with a higher expected impact, while the additional expected impact of collaborating with Danish industry is small or even slightly negative, depending on the field.

Concerning collaboration with Danish private business, there is a lot of variation in results across fields. Coefficient estimates are positive and significant within physics and mathematics and engineering and materials, and negative within both medical fields (health sciences and biomedicine). Overall, and within chemistry and agriculture, the coefficient is insignificant.

In contrast, collaboration with a foreign business is positive and significant in almost all cases (only exception being agriculture). Fig. 3 shows that for all sciences, that the expected impact measured of a publication is 18.5% higher for articles with international industrial authors and Danish authors compared to only publications with only Danish authors.

The interaction of international public research and international industry is included in order to see whether there is an extra boost in citation impact for multi-partner collaborations involving both of these types. The number of publications with both of these types of collaborations is small compared to other groups of publications, leading to wide confidence intervals. However, despite this, coefficients for all fields is clearly positive and significant. Interestingly, this result appears however to be driven by only one field, health sciences.

4.1.3. Selection bias

There are many reasons we cannot assume a causal relationship between the independent and dependent variables. One of these is selection into international and industrial collaborations; if successful researchers are more likely to collaborate with industry and international partners we would also expect that the research produced would be above average. Thus, the researchers' ability is the driver of the observed effects. In the next analysis, we attempt to investigate whether this can explain some of the observed differences.

5. Analysis at the level of the individual researcher

The goal of this sub-section is to examine to which degree the impact of public-private collaboration can be explained by selection bias, where firms choose to collaborate with high performing researchers. We identify a group of corresponding authors of articles involving both public-private collaboration and public research collaboration and construct a list of all

Table 3
Distribution of individuals according to number publications.

Number of publications by author	2–5	6–10	11–19	20+	Total	Number publications
Number of authors	177	133	161	276	747	17,973

articles authored by the group of researchers within a period of time. In doing so, we are able to see how articles with public-private collaboration compare to academic-only articles authored by the same researchers.

The sample examined in this paper consists of all corresponding authors with a Danish address with an article in 2008–2010 involving public-private collaboration, which amounts to 798 researchers.[6] For each of the 798 researchers, publication portfolios over the period 2006–2012 were collected in the Science and Social Science Citation Indices of Web of Science (WoS) using a name disambiguation algorithm developed by CWTS that has generally shown very high recall rates (90–95%) especially with sets of non-Asian author names and affiliations (Caron & van Eck, 2014).[7] However, it is still important to note that this process is not perfect where both incomplete lists and false positives are possible. The length of the time period was chosen with the intention of having as short a period as possible that could at the same time produce a sufficient number of articles per person to facilitate the analysis. By minimizing the duration of the period, we hope to restrict development in research experience over time. We limit the analysis to papers that have at least two co-authors, in order to compare the type of collaborative articles. Single authored papers will only appear in Type 1, and since we know that the number of authors is related to citation impact, we remove these from the analysis. Of these 798 researchers (and after removal of single author papers), 51 had only one publication with collaboration during the period, which precludes the possibility of any comparison across types of collaboration. Hence, we removed them from the sample.

17,973 articles were identified over the period 2006–2012 for the 747 researchers. Table 3 shows the distribution of individuals according to number of publications.

In general, citation impact is typically much higher for papers involving international collaboration. Hence, we want to take account of international collaborations in the analysis here, utilizing the classification of collaborations mentioned in the methods, except for type 5, industrial research.

We first conduct an aggregated analysis, where we calculate the mean normalized citation score (MNCS), for the entire subset of papers for each of these four types of collaboration. This subset of papers has in common that they include the same group of researchers as co-authors. However, it is clear that our approach here does not ensure that all co-authors are the same within each collaboration type, so this attempt to 'level the field' in terms of the researchers involved is only partially successful.

Secondly, we compare citation impact for the individual researcher. For each researcher covered in our sample, we calculate MNCS for the researcher's publications in each of the four categories. We make pairwise comparisons of different types of collaboration in order to ensure that we are comparing the same group of researchers. So, when we for example compare MNCS for Danish public research papers with Danish public-private collaborations, we only include researchers that have publications in both of these groups. In order to be as inclusive as possible, we only require that one publication is needed in a category in order to calculate the MNCS for the individual researcher.

Finally, it is important to keep in mind that this data is highly skewed, which calls into question the validity of tests that assume that the data is normally distributed. While there are differing opinions on how extreme the skewness should be before precluding the use of t-tests in practice, it may be more appropriate to use non-parametric tests that essentially test whether overall distributions for two groups are equal. In the following, we report results of both tests.

5.1. Comparisons of means and medians

The main results of this analysis are shown in. Table 4 The table shows the results of pairwise comparisons of MNCS within the four types of collaborations. Industry only papers are not included here as only a small number of researchers have these papers and a comparison would thus not be generalizable in any meaningful way.

As noted above, comparisons are only made for researchers that have publications in both types of collaboration. For example, the first comparison is Danish public research papers vs. Danish public-private collaborations. Of the in all 747 researchers in the sample, 500 have at least one paper in each of these two groups. The table shows the average MNCS per researcher and median value of MNCS for this group of 500 researchers. We have conducted both standard t-tests and non-parametric SignRank tests on the data. Confidence intervals (95%) for the test statistics are shown in the table.[8]

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[6] Due to data availability, it is more feasible to match other publications with the corresponding authors than with other authors.

[7] The collection of individual publication portfolios was performed by CWTS, Leiden University.

[8] Note: Estimates of difference in medians and confidence intervals for SignRank are based on Somers' D, which is an asymmetric measure of association between two variables (see Newson, 2006), and is thus not fully equivalent to the SignRank. Whereas SignRank essentially tests the equality of distributions for two variables, SomersD can be interpreted as a measure of the effect size between the two variables, and their confidence intervals.

Table 4
Comparison of mean and median values per individual -Results of non-parametric and parametric tests.

		Full count MNCS											
	obs	Median	Sign-Rank [95% CI]		Mean	T-test [95% CI]		Median	Sign-Rank [95% CI]		Mean	T-test [95% CI]	
National public-private	545	0.82			1.24			0.80			1.24		
National public	545	0.98			1.21			0.98			1.19		
Difference		−0.04	−0.14	0.07	0.03	−0.10	0.16	0.00	−0.10	0.10	0.05	−0.18	0.09
Interinational public	500	1.14			1.45			1.09			1.36		
National public	500	1.01			1.28			1.01			1.27		
Difference		0.10	0.00	0.21	0.17	−0.01	1.09	0.14	0.04	0.25	0.09	−0.10	0.27
National public	422	1.01			1.29			1.01			1.28		
International public-private	422	1.23			2.20			1.16			1.98		
Difference		−0.31	−0.43	−0.20	−0.91	−1.50	−0.32	−0.25	−0.37	−0.14	−0.70	−1.27	−0.13
National public-private	472	0.84			1.27			0.83			1.26		
International public	472	1.12			1.38			1.08			1.29		
Difference		0.03	−0.08	0.14	−0.11	−0.28	0.07	0.03	−0.08	0.14	−0.03	−0.20	0.14
National public-private	404	0.85			1.27			0.83			1.27		
International public-private	404	1.23			2.22			1.16			2.00		
Difference		−0.14	−0.25	−0.03	−0.95	−1.56	−0.34	−0.15	−0.26	−0.03	−0.73	−1.31	−0.14
International public	416	1.17			1.46			1.12			1.38		
International public-private	416	1.25			2.22			1.20			1.99		
Difference		−0.24	−0.36	−0.13	−0.76	−1.34	−0.17	−0.14	−0.25	−0.02	−0.61	−1.17	−0.04

Consider first the comparison of national public articles and national public-private articles. Mean values are fairly close to one another. In contrast, the median value for national public articles is much larger than for national public-private. However, the confidence interval includes zero.

The comparison for other types of collaboration is more straightforward. For example, in comparison of national public articles with international public articles, international collaboration has both a significantly higher mean and the overall distribution is also significantly higher in terms of MNCS. The same result holds when comparing national public research with international public private. MNCS for inter-national public-private collaboration is clearly higher than for other collaboration types, and is thus in line with expectations from the regression results for the full sample of Danish research articles from 1995 to 2013.

We can briefly summarize and simplify the findings for individual researchers. The expected impact of an article for individual researchers is lowest for National public research articles, only minutely higher impact can be expected from a national public private publication, whereas a international public publication has a higher expected impact and a international public private publication has highest expected impact. Thus, the results indicate that collaborating internationally and with industry is related to a higher expected impact. However, what should also be kept in mind is that no matter what type of co-authoring team the most common number of citations is zero.

6. Conclusions

In this paper, we have addressed the question of whether public-private collaboration is beneficial or detrimental to scientific research from various angles. For national collaboration papers, we find no significant difference in citation impact for public-only and public-private collaborations. For international collaboration, we observe much higher citation impact for papers involving public-private collaboration. This raises the question of whether it is the international collaboration rather than the public-private which adds to the increased impact. Furthermore, our results indicate that the observed differences are mainly driven by the health sciences, suggesting that citation impact is particularly high among articles based on large-scale clinical studies.

These observations are supported further by our regression analyses. Taking into account known factors influencing the citation impact of publications, as well as variation over time and field, the largest predictor is the presence of international collaboration. There is some variation across fields as to how large the effect of this predictor is, where the effect is largest in health science and biomedical research. At the same time, Danish research within agriculture, fisheries and forestry as well as physics and mathematics does not on average have large citation impact for this collaboration type. The effect of a private, international collaborator varies vastly across fields, which may in part be explained by the relatively low number of observations with international public-private collaboration.

As for the number of authors, a factor previously identified as a driver for citation impact, international and public-private collaborations tend to have a greater number of co-authors, and we find that citation impact is increasing in the number of co-authors. However, controlling for number of authors does not affect our basic results concerning relative citation impact for different types of collaboration.

Our findings on the differences between clinical and biomedical research could suggest a difference in citation and publication behavior for applied and basic research within a given field. These differences are not necessarily accounted for when field-normalizing citation scores, which do not differentiate between basic and applied work within a given field. A further investigation of this topic, however, would require a much more precise categorization of basic and applied research than the approximation used here.

Our analysis of journal article citation impact with different collaborative constellations shows that the differences found in the regression, cannot be attributed to self-selection into industrial and international collaboration of high performing researchers, as the effects of international and public-private collaboration are also present when controlling for author fixed effects.

The international dimension thus remains the strongest factor for citation impact. This reflects a number of factors, such as greater visibility and potential positive benefits on research from international collaboration. It may also reflect an increasing tendency among researchers to seek international collaboration, a trend that may be greater among the most promising researchers.

Bibliometric analysis of public-private collaboration only shows a limited perspective on the topic. There are other benefits and costs, tangible or not, associated with these collaborations. These are all relevant parts of an ongoing discussion in which our contribution should be seen as only one part of the puzzle.

In sum, one could ask what the implications of our analyses are for policy, where there is an ever increasing emphasis on promoting public-private collaboration in research. One concern is that a strong focus on public-private collaboration can be detrimental for researcher careers, as it may hurt their research performance, which is often measured in terms of citation impact. Our analysis does not show any indication that a focus on industry collaboration leads to lower impact. Impact for national public research and national public-private research are similar, and impact for international public-private research is very high. An alternative interpretation of our analysis is that promotion of international public-private collaboration leads to higher impact. Both international collaboration in general and international public and private research in particular are clearly associated with higher citation impact on average.

Author contributions

Carter Bloch: Conceived and designed the analysis; Collected the data; Contributed data or analysis tools; Performed the analysis; Wrote the paper.

Thomas K. Ryan: Conceived and designed the analysis; Collected the data; Contributed data or analysis tools; Performed the analysis; Wrote the paper.

Jens Peter Andersen: Conceived and designed the analysis; Collected the data; Contributed data or analysis tools; Performed the analysis; Wrote the paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.joi.2019.03.003.

References

Behrens, T. R., & Gray, D. O. (2001). Unintended consequences of cooperative research: Impact of industry sponsorship on climate for academic freedom and other graduate student outcome. *Research Policy*, *30*(2), 179–199. http://dx.doi.org/10.1016/S0048-7333(99)00112-2

Bloch, C. W., Andersen, J. P., Ryan, T. K., & Schneider, J. W. (2017). *Collaboration in research* Copenhagen.

Bloch, C. W., Ryan, T. K., & Andersen, J. P. (2016). Public-private collaboration and scientific impact: An analysis at the level of the individual researcher. *Proceedings of the 21st international conference on science and technology indicators*, 733–740.

Bozeman, B., Fay, D., & Slade, C. P. (2013). Research collaboration in universities and academic entrepreneurship: The-state-of-the-art. *The Journal of Technology Transfer*, *38* http://dx.doi.org/10.1007/s10961-012-9281-8

Caron, E., & van Eck, N. J. (2014). Large scale author name disambiguation using rule-based scoring and clustering. *Proceedings of the science and technology indicators conference 2014*, 79–86.

D'Este, P., & Perkmann, M. (2011). Why do academics engage with industry? The entrepreneurial university and individual motivations. *The Journal of Technology Transfer*, *36*(3), 316–339. http://dx.doi.org/10.1007/s10961-010-9153-z

Danish Ministry of Higher Education and Science. (2018). *Forskningsbarometeret 2017. Årlig statistik og analyse om forskning og innovation.*

Etzkowitz, H. (2003). Research groups as "quasi-firms": The invention of the entrepreneurial university. *Research Policy*, *32*(1), 109–121. http://dx.doi.org/10.1016/S0048-7333(02)00009-4

Glänzel, W., & Schubert, A. (2001). Double effort = double impact? A critical view at international co-authorship in chemistry. *Scientometrics*, *50*(2), 199–214. http://dx.doi.org/10.1023/A:1010561321723

Godin, B., & Gingras, Y. (2000). Impact of collaborative research on academic science. *Science & Public Policy*, *27*(1), 65–73.

Katz, J. S., & Hicks, D. (1997). How much is a collaboration worth? A calibrated bibliometric model. *Scientometrics*, *40*(3), 541–554. http://dx.doi.org/10.1007/BF02459299

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy*, *26*(1), 1–18. http://dx.doi.org/10.1016/S0048-7333(96)00917-1

Larivière, V., Gingras, Y., Sugimoto, C. R., & Tsou, A. (2015). Team size matters: Collaboration and scientific impact since 1900. *Journal of the Association for Information Science and Technology*, *66*(7), 1323–1332. http://dx.doi.org/10.1002/asi.23266

Lebeau, L. M., Laframboise, M. C., Larivière, V., & Gingras, Y. (2008). The effect of university-industry collaboration on the scientific impact of publications: The Canadian case, 1980–2005. *Research Evaluation*, *17*(3), 227–232. http://dx.doi.org/10.3152/095820208X331685

Liu, H. I., Chang, B. C., & Chen, K. C. (2012). Collaboration patterns of Taiwanese scientific publications in various research areas. *Scientometrics*, *92*(1), 145–155. http://dx.doi.org/10.1007/s11192-012-0719-4

Lundberg, J. (2007). Lifting the crown - citation z-score. *Journal of Informetrics*, *1*(2), 145–154. http://dx.doi.org/10.1016/j.joi.2006.09.007

Newson, R. (2006). Confidence intervals for rank statistics: Somers' D and extensions. *The Stata Journal*, *6*(3), 309.

NordForsk. (2014). *Comparing research at Nordic Universities using bibliometric indicators: Second report, covering the years 2000–2012* Oslo.

Owen-Smith, J. (2003). From separate systems to a hybrid order: Accumlative advantage across public and private science at Research one universities. *Research Policy*, *32*(6), 1081–1104.

Perkmann, M., & Walsh, K. (2009). The two faces of collaboration: Impacts of university-industry relations on public research. *Industrial and Corporate Change*, *18*(6), 1033–1065. http://dx.doi.org/10.1093/icc/dtp015

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., . . . & Sobrero, M. (2013). Academic engagement and commercialisation: A review of the literature on university-industry relations. *Research Policy*, *42*(2), 423–442. http://dx.doi.org/10.1016/j.respol.2012.09.007

Persson, O., Glänzel, W., & Danell, R. (2004). Inflationary bibliometric values: The role of scientific collaboration and the need for relative indicators in evaluative studies. *Scientometrics*, *60*(3), 421–432.

Slaughter, S., & Leslie, L. L. (1997). *Academic capitalism: Politics, policies, and the entrepreneurial university*. Baltimore: The Johns Hopkins University Press.

Sørensen, M. P., & Schneider, J. W. (2017). Studies of national research performance: A case of "methodological nationalism" and "zombie science"? *Science & Public Policy*, *44*(1), 132–145. http://dx.doi.org/10.1093/scipol/scw043

Thelwall, M., & Wilson, P. (2014). Regression for citation data: An evaluation of different methods. *Journal of Informetrics*, *8*, 963–971.

Van Raan, A. F. J. (1998). The influence of international collaboration on the impact of research results. *Scientometrics*, *42*(3), 423–428.

Waltman, L. (2016). A review of the literature on citation impact indicators. *Journal of Informetrics*, *10*(2), 365–391. http://dx.doi.org/10.1016/j.joi.2016.02.007

Waltman, L., & van Eck, N. J. (2015). Field-normalized citation impact indicators and the choice of an appropriate counting method. *Journal of Informetrics*, *9*(4), 872–894. http://dx.doi.org/10.1016/j.joi.2015.08.001

Waltman, L., & Van Eck, N. J. (2013). A systematic empirical comparison of different approaches for normalizing citation impact indicators. *Journal of Informetrics*, *7*(4), 833–849. http://dx.doi.org/10.1016/j.joi.2013.08.002

Waltman, L., Calero-Medina, C., Kosten, J., Noyons, E. C. M., Tijssen, R. J. W., van Eck, N. J., . . . & Wouters, P. F. (2012). The Leiden ranking 2011/2012: Data collection, indicators, and interpretation. *Journal of the American Society for Information Science and Technology*, *63*(12), 2419–2432. http://dx.doi.org/10.1002/asi.22708

Wuchty, S., Jones, B. F., & Uzzi, B. (2007). The increasing dominance of teams in production of knowledge. *Science*, *316*(5827), 1036–1039. http://dx.doi.org/10.1126/science.1136099

Chapter 8: Perspectives on the empirical and theoretical contributions

In this concluding chapter, I discuss the main empirical and theoretical contributions of this dissertation and how they address the main research question: *"How is the production and public dissemination of scientific knowledge affected by the participation of industry in academic research?"*. In addition, I outline future research avenues that may enhance our understanding of the relevant mechanisms that are at play in university-industry interactions concerning knowledge production, impact and dissemination. Finally, I discuss the policy implications of the empirical findings.

The overall research question has motivated a series of sub-research questions examined in the dissertation. Chapter 4 addressed RQ1.a: "How is the decision to publish knowledge outcomes in university-industry projects determined?" Motivated to understand when and under which circumstances project partners in university–industry projects decide to publish scientific findings, the chapter provided a conceptualization of the publication decisions in university-industry projects. Based on the "economics of science" approach and empirical and theoretical contributions in various fields, I argued how the knowledge outcome, legal setting and partnership characteristics may influence publication decisions. Chapter 5 examined RQ1.b: "To what degree do university-industry projects lead to the dissemination of knowledge outcomes in academic literature, and is the propensity to publish related to specific project characteristics or the type of project?" Utilizing unique access to a university database, 177 university-industry projects were analysed and coded based on project documents including contracts, project descriptions and budgets. The chapter analyzed the relationship between project objectives and dissemination of knowledge in the sample of university-industry projects and explored whether the degree of industry participation and contribution to projects was related to dissemination in university-industry projects. Chapter 6 examined RQ2: "To what extent do academics pursue different objectives and produce qualitatively different academic outputs within university-industry projects compared to their purely academic research?" I expanded on the database used in chapter 5 by adding bibliographic information to publication lists of academic project participants. The chapter provided an empirical analysis of the degree to which publications produced in the context of university-industry projects were similar to or different from academics' other publications in terms of textual content and knowledge base. Chapter 7 examined

RQ3: “How does collaboration with industry influence the impact of academic research?” Based on Danish Publication data for 1995-2013, the chapter examined the citation impact of papers involving public-private collaboration in comparison with academic research papers. It investigated whether publications with industrial co-authors had different expected impact compared to publications with only public research organizations.

8.1 Findings and contributions

In the following, I discuss the key findings of this dissertation and how they shed light on the relationship between firm participation in academic research and the direction of research, its dissemination, and impact on scientific knowledge. In particular, the empirical studies in this dissertation indicate three general findings: 1) Academic research performed with industry tends to be peripheral to what academics generally pursue. 2) The type of project in terms of objective and degree of firm participation relates to the propensity to publish research in scientific literature. Importantly, the majority of projects that are not focused on problem solving lead directly to published research. 3) The expected impact of publications co-authored with industry is similar to the expected impact of similar research co-authored with other academics. However, publications co-authored with foreign firms based abroad has a higher expected impact than both national and international public co-authored publications. In the following, I expand on the findings and their contributions.

8.1.1 Dissemination

The research question ”To what degree do university-industry projects lead to the dissemination of knowledge outcomes in academic literature, and is the propensity to publish related to specific project characteristics or the type of project?” (RQ1.b) is analysed in Chapter 5. Based on the analysis of 117 university-industry projects, I find that the majority of university-industry projects, regardless of project type, lead to at least one publication (indexed in web of science). Overall, projects with a high degree of finalization (projects with commercial and market-oriented objectives) lead to comparably fewer project-related publications than projects with a low to moderate level of finalization. Thus, projects that focus on solving technical and practical problems for firms were less likely to lead to published research than projects that focused on exploring new ideas and researching natural phenomena. Moreover, the degree of firm participation and contribution to projects was associated with lower propensities to publish. Thus, when firms fund directly or in-kind a high proportion of a project the propensity to publish decreases. While firm participation and finalization are correlated, firm participation still has a negative relationship with publication propensity when controlling for finalization,

The central argument in Perkmann and Walsh (2009) is that higher degrees of finalization are related to secrecy issues and academic relevance of projects. While chapter 5 found that project finalization and the propensity to publish were related, the patterns in the sample of projects studied in chapter 5 did not indicate that project finalization and publication behavior had a proportional relationship as described in Perkmann and Walsh. As soon as a university-industry project is one-step removed from pure consultancy and problem solving objectives, the differences in publication propensity were only marginal. Thus, whether the project focuses on technology development, ideas testing or knowledge generation only relates to project-related publication outcomes to a limited extent. The analyses indicate that while finalization can predict some variation in publication outcomes, the degree of economic contribution and actual participation of firms is an important predictor of publishing propensity in university-industry projects. The higher the contribution and participation from firms, the lower the probability that the project leads to publications, the lower the number of project related publications and the longer time until the first project related publication is published. This relationship holds both for analyses with and without measures of finalization.

The results suggest that academic project participants appear to be able to pursue research relevant to their field in projects where publishable research is not the primary objective. It indicates that researchers co-design projects or select into projects that have the potential to generate knowledge and enable discoveries relevant to their field. To the question, "How is the decision to publish knowledge outcomes in university-industry projects determined? (RQ1.a) in Chapter 4, I presented a conceptualization of the publication decision in university-industry projects. Based on the assumptions that academics have an incentive to publish scientific findings and that firms maximize returns to commercially relevant knowledge through secrecy, I argued that the choice of publication in a university-industry project depends on how each party valued the partnership, the division of property rights and the nature of the knowledge produced. Transferring the result of the analysis in chapter 5 to the conceptual framework in chapter 4, the publication pattern could reflect that while secrecy issues may occur, firms value the partnership to such a degree that they ´allow´ academics to publish. Alternatively, there may be a division of intellectual property rights prior to the project that enables academics to choose to publish relevant outcomes. Yet, when firms invest highly in projects, knowledge outcomes may be steered towards commercial uses and secrecy may be important to obtain a sufficient return on their investment. In the analysis in chapter 5, I cannot pin-point however, whether the relationship between publication propensity and project objective and firm participation is due to the type of research produced or the pressures of secrecy or a combination hereof.

The study in chapter 5 contributes to the literature on university-industry collaboration by enhancing our understanding of what types of projects are related to and thus conducive to academic knowledge production and publishing. Moreover, the study illustrates how using novel contract databases can illuminate the intricacies of university-industry projects. By focusing on the diversity of university-industry projects instead of implicitly viewing them all as part of one uniform group and assessing the average effect on academic productivity of academic engagement, we can better understand when and under which circumstances engaging with firms can be complementary to academic research.

8.1.2 Direction

To the question of whether the direction of academic research is affected by the participation of industry in the research process (RQ2), Chapter 6 examined the similarity of publications produced within university-industry projects to the remaining publication portfolio of engaged academics. The study investigates the degree to which publications produced by engaged academics within university-industry projects differ in terms of content and knowledge base from their published research in general. Exploiting a database of academics engaged in university-industry projects, the study compares the similarity of publications produced by academics in two different contexts. Measures include text based and bibliographic based cosine similarity measures. The analysis found that research published in university-industry projects tended to be peripheral to academics' portfolio in general. This study was unable to tease out potential mechanisms or to attempt to track and understand behavior. However, I argue that the result lends some credence to the idea that firm participation may skew or affect the direction of research. I argue that the findings indicate that academics either actively interact with industry to explore areas outside their main area or are pushed or pulled towards new areas of research when interacting with industry. A sub-analysis revealed that academics from disciplines within "applied sciences" where more likely to produce research that was peripheral to their general profile than those from disciplines within "basic sciences". However, one should be careful in interpreting this result, as it is a coarse classification. This result is quite puzzling, as one would expect that it is academics in applied sciences who tend to perform less similar research with industry, while academics in basic sciences tend to perform similar research. It could suggest that academics in basic sciences may tend to engage with industry only when it is fits well with their research agenda, while academies in applied sciences are interested in or willing to move their focus in order to investigate other topics and problems either to obtain funding or out of interest.

The study in chapter 6 provides much needed empirical evidence to a concern that is often voiced regarding university-industry collaboration, namely that firms can directly or indirectly steer research towards short term goals at the expense of longer term scientific and innovation development. While the chapter contributes with evidence to the difference in content and knowledge base between knowledge created with and without industry it cannot provide answers to this concern. However, the results provide an important stepping stone for further work. Future work could include studies with a larger sample that is more balanced and includes a wider set of disciplines and nationalities, along with qualitative interviews to better understand researchers' motivations for pursuing university-industry collaborations, and to what extent this involved changes in the objectives and conduct of their research.

8.1.3 Impact

To the question "How does collaboration with industry influence the impact of academic research?" (RQ3), the analysis of the impact of co-authored publications in Chapter 7 found no difference between the expected impact of national public-private and national public publications. However, we found that international public-private publications have the highest expected impact. The study adjusted for a range of known factors influencing the citation impact of publications. Additionally, a sub-study of the publications of 747 academics attempted to control for potential selection bias. The study indicated that research produced with industry partners from abroad generally are cited more than any other types of collaborations. We found that the international dimension is the strongest predictor of citation impact. We cannot provide an empirically grounded answer to why these patterns emerged, however we speculate that this may relate to the type of collaborations that are performed with foreign actors, including firms. For example, the importance of the international dimension may relate to the visibility of research and that the expected outcome from international collaborations may have to be relatively high before investing in this relatively more costly form of collaboration. As the impact of collaborations with domestic firms is very similar to that of public-only co-authorships, simply collaborating with firms in general cannot be the reason for the higher expected impact. In Chapter 6, a descriptive analysis found that on average university-industry publications received a lower normalized citation impact than academics' other publications. While these findings in chapter 6 may seem contradictory to the findings in chapter 7, this need not be the case. First of all, the publications examined in Chapter 6 where not necessarily co-authored with firms as they were directly linked to a project. Moreover, in Chapter 7 we found that the differences in expected impact were highest within the health sciences, while they were smaller within the technical and natural sciences investigated in chapter 6. Moreover, most of the university-industry projects in the sample in chapter 6 consisted of national collaborations. In the analysis in Chapter 7, when comparing the impact of academics' publications with and without domestic firms, the median impact is substantially lower with firms, while the mean impact is similar. Thus, in the sample analyzed in Chapter 7 the average was driven by a small set of publications with industry that had very high citation rates, while most publications received fewer citations when they were published with domestic industry.

The findings in Chapter 7 contribute to our understanding of the relationship between scientific impact and collaboration. While previous research has examined this relationship, this study provides more efficient estimates by controlling for confounding variables not addressed I previous research. From the analyses in this dissertation, there is limited evidence to suggest that collaborating with firms and co-authoring with firms is associated with substantially higher or lower citation impact. However, collaborations with domestic firms is associated with a lower expected impact than collaboration with international firms. This is a finding that should be investigated more thoroughly in future research.

8.2 Empirical challenges and limitations

The conclusions of this study are based on empirical analyses of samples of academics, projects and published research. The empirical results and the conclusions are therefore limited by the sample selection and their contexts. Moreover, the empirical studies are largely quantitative and focused on correlational evidence; therefore, the dissertation has limitations in its ability to provide in depth explanations of the causal mechanisms that may be at play.

The greatest challenges in understanding how firm participation in academic research affects the direction, impact and dissemination decisions in university-industry projects is that academics self-select into these types of projects. It is not possible to observe, at least with the methods used in this dissertation, whether "non-publication" in a project is related to the secrecy concerns or to the fact that knowledge produced in a specific university-industry project is not publishable in scientific journals. Similarly, while differences within and outside of university-industry projects in the type and content of research pursued and produced and its impact can be estimated, the counterfactual activity is not available. Hence, I cannot provide causational claims between the type of project and the outcomes. In this dissertation, I offer mostly correlational analyses that are unable to provide direct, causal evidence to how firm participation may affect academic research. However, I do in the empirical studies attempt to control for measureable confounding factors in order to improve comparability. Therefore, the work of this dissertation provides indications rather than hard conclusions concerning how firm participation in research through university-industry projects affects the direction of research, the dissemination of research and the impact of research. A clear limitation of this dissertation is the difficulty in attributing cause and explaining why we see the patterns that we do.

The empirical studies in this dissertation are focused on specific samples and groups of individuals within a certain context. In Chapter 5 and Chapter 6, the samples are limited to a single university faculty and therefore, specific fields of science are not represented in the data. Thus, the findings are mainly relevant to the areas of science investigated, namely the technical and natural sciences. Moreover, the Danish case may have some specificities and peculiarities that differ from other context. While this is not different to earlier studies, this offers similar limitations to the generalizability of the findings. The degree to which the findings in these studies are observable outside the case of Denmark and the faculty of science and technology is unknown. I argue however that the cases bear various similarities to other contexts that can enable careful generalizations to a wider population.

In the analyses in both Chapter 5 and Chapter 6, an additional limitation of the analysis is restrictions due to the confidential nature of the data. This created some limitations in both the way in which the data could be analyzed and how it is communicated in this dissertation. For example, data confidentiality prevented the qualitative analysis in Chapter 5 from being coded by a second coder. Moreover, it meant that I could not contact project initiators to confirm publication lists. Including such methodologies to the analysis could have improved the quality of the work.

A challenge in the study of outcomes from university-industry projects is the identification of said outputs. In chapters 5 and 6, I use a different methodology than in Chapter 7. Earlier studies have relied on surveys and self-reported outcomes, which serve different challenges.

8.3 Open questions and future research avenues

In Chapter 5, I find that the propensity to publish differs between projects. This includes both the objective and the degree of firm participation in projects related to the propensity to publish project related publications. I conjecture in the chapter on reasons for why this correlation is observed, though the empirical material available cannot provide an opportunity to explore potential explanations. Therefore, I argue that future research should examine to what degree the difference in publication propensities is driven by secrecy issues, the lack of “scientific relevance” or other potential explanations. The conceptual framework developed in Chapter 4 provides a starting point from which studies could examine the publication decision and factors such as the importance of the relationship between partners, the contractual division of property rights and the characteristics of knowledge outcomes. Understanding how these complexities influence the publication decision can aid in policy decisions and organizational architecture for facilitating university-industry projects that achieve both scientific and industrial benefits.

In Chapter 6, the results pointed to research outcomes being peripheral to that of academics researchers’ general publication portfolio. Future research should explore to what extent research content is different due to academics’ self-selection into different research avenues, whether they are pulled in certain directions due to funding availability or to what extent it is the diverse set of partners and the process of working with firms that leads to different types of outcomes. Moreover, future research should evaluate qualitatively the potential benefits and costs of research being pushed or pulled in new directions.

An additional question is what drives the large difference in citation impact between domestic and international public-private collaborations. The time perspective could be interesting to assess; for example, whether collaborations with international firms is something that happens later in the career when academics have gained high status in their environment, driving visibility and impact up (Mathew effect).

8.4 Policy implications

A main motivation of this dissertation was to provide a better and more nuanced understanding of the potential academic consequences of the political focus on increasing and facilitating university-industry interaction. Generally speaking, there is an understanding that an interaction has both benefits to the economy and to science itself, while potential issues regarding direction of research and secrecy are either downplayed or ignored in political rhetoric. A similar analysis could be made related to extant literature, which often briefly discusses potential limitations and unintended consequences of university-industry projects, thereafter concluding that on average there are benefits to academic research. While university-industry collaboration may have various benefits to innovation and society in general, the results from this dissertation indicate that the notion that interaction with industry should improve the impact of science is not obvious. At least when measuring citation impact. As such, improving the impact of scientific work through university-industry collaboration cannot be used as an additional political argument for increased interaction between firms and academics. If, such an argument should be used it should likely focus efforts on increasing international collaboration with firms. However, since causality is difficult to assign, expecting higher impact research from incentivizing more international collaboration may not have the intended consequence. In conclusion, if the impact of research is the goal, there is nothing in this dissertation to suggest that incentivizing increased interaction with domestic firms at least will lead to more impactful research.

My research indicates however, that the type of projects that are incentivized will affect the degree to which knowledge is produced and disseminated. If the goal is to facilitate research with industry that is made publicly available, then projects that have a high degree of firm participation and contribution or are highly finalized are likely projects that should not receive most incentives. However, these types of projects may offer other benefits to society, academia and industry.

Finally, research with industry likely entails a specific type of research that is different to what academics would pursue otherwise; therefore, a deeper understanding of what this research is and what it leads to is necessary to understand the consequences for research of incentivizing such interactions. Politically, it is important to recognize that incentivizing interaction with industry through e.g. industrial PhDs and post docs likely means that the type, objective and content of research will be different from research performed within the confines of academia. Whether different is good, bad or neutral is however, a question that both needs more research and one that is heavily normative.

Summary

While university-industry collaboration is not a new phenomenon, interaction between academics and firms has become increasingly commonplace throughout academia. In many countries, research and innovation policy has focused on promoting and facilitating interaction between academics and firms, with the expectation that such interaction will provide both economic and scientific benefits. The importance of public research for innovation is well-established (Mansfield, 1998; Nelson, 2004; Salter & Martin, 2001). Yet, how university-industry collaborations affect the direction and impact of academic research and the public dissemination of scientific knowledge is less well-understood.

There are conflicting views on how university-industry collaboration may affect academic research. On one hand, scholars argue that engagement with industry is generally conducive and complimentary to traditional academic research activities (D'Este et al., 2013; Markus Perkmann et al., 2021; M. Perkmann, Tartari, McKelvey, Autio, Broström, et al., 2013). (Markus Perkmann et al., 2021; M. Perkmann & Walsh, 2009). On the other hand, critical voices argue that interaction with industry may have unintended consequences for academic research. University-industry collaboration may influence both the direction and focus of academic research and that relevant research outcomes may be kept from the public due to the commercial interests of industrial partners (Behrens & Gray, 2001; Florida, 1999; Krimsky, 1999; Slaughter & Leslie, 2001)

This dissertation examines the overarching research question: how is the production and public dissemination of scientific knowledge affected by the participation of industry in academic research within university-industry projects. Empirically situated in a Danish context the dissertation aims to understand how the direction of academic research and the dissemination and impact of scientific knowledge is affected within the context of university-industry projects. Through empirical analyses of university-industry projects and publication data as well as a conceptualization of the publication decision in university-industry projects the dissertation addresses four sub-research question related to the general research question. The findings provide an empirical basis to discuss whether the focus on promoting interaction between academics and firms may have unintended or negative consequences for scientific knowledge production and a discussion of the potential mechanisms that affect the publication of research within university-industry projects.

Previous empirical work has explored the academic consequences of engaging in activities with industry (Larsen, 2011; Markus Perkmann et al.,

2021; M. Perkmann, Tartari, McKelvey, Autio, Brostrom, et al., 2013). However, these studies generally do not directly investigate how and to what degree academic knowledge is produced within university-industry projects. Building on previous studies on university-industry projects this dissertation examines the extent to which projects lead to publications depending on their objective and the degree of firm's participation in a sample of 117 university-industry projects.

Scholars have argued that interaction with industry may cause academic research to move towards more short-term, application-oriented research at the expense of fundamental scientific inquiry (Florida, 1999; Geuna, 2001). Yet empirically, there is little evidence and limited empirical research with regards to whether academics' publish research that is different within university-industry projects than in their academic collaborations. This dissertation offers an empirical analysis of this question in a study of the publication content produced by 115 academics engaged in university-industry projects.

Inspired by the mainly politically motivated discussion, previous studies have attempted to assess the impact of knowledge outcomes of university-industry collaboration. While a handful of studies have focused the impact of publications co-authored or co-produced by firms and academics (Lebeau, Laframboise, Lariviere, et al., 2008), they are largely correlational and do not fully take potential confounding factors into account in their studies. In this dissertation, the question of impact and university-industry collaboration is explored in an analysis of Danish publications published between 1995-2013 taking into account factors that are known to correlate with impact, and thus provide a more efficient estimate on the relationship between university-industry collaboration and citation impact.

The empirical studies in this dissertation indicate three general findings: 1) that academic research performed with industry tends to be peripheral to what academics generally pursue, 2) that the type of project in terms of objective and degree of firm participation relates to the propensity to publish research in scientific literature, and 3) that the expected impact of publications co-authored with industry is similar to the expected impact of similar research co-authored with other academics. However, publications co-authored with foreign firms based abroad has a higher expected impact.

My research indicates that the type of projects that are pursued likely affect the degree to which knowledge is disseminated and the direction of research. Politically, if a goal of promoting university-industry collaboration is to facilitate research that is made publicly available, then projects that have a high degree of firm participation and contribution or are highly finalized are likely projects that should not receive most attention. However, these types of projects may offer other benefits to society, academia and industry. Finally, research with industry likely entails a specific type of research that is different to what academics would pursue otherwise; therefore, a deeper understanding of what this research is and what it leads to is necessary to understand the consequences for research of incentivizing such interactions. Politically, it is important to recognize that incentivizing interaction with industry likely means that the type, objective and content of research may be different from research performed within the confines of academia. Whether different is good, bad or neutral is however, a question that both needs more research and one that is heavily normative.

Resumé

Selvom offentlig-privat samarbejde ikke er et nyt fænomen, er interaktion mellem akademikere og virksomheder blevet mere og mere almindelig. I mange lande har forsknings- og innovationspolitik fokuseret på at fremme og understøtte interaktion mellem akademikere og virksomheder med en forventning om, at det vil give både økonomiske og videnskabelige fordele. Den offentlige forsknings betydning for innovation er veletableret (Mansfield, 1998; Nelson, 2004; Salter & Martin, 2001), hvorimod vores viden om hvordan offentlig-privat samarbejde påvirker retningen og gennemslagskraften af akademisk forskning og formidling af forskningsresultater er mere usikker.

Der er modstridende synspunkter om, hvordan samarbejde mellem universitet og virksomheder kan påvirke akademisk forskning. På den ene side hævder forskere, at samarbejde og interaktion med industrien generelt er befordrende og komplementær til traditionelle akademiske forskningsaktiviteter (D'Este et al., 2013; Markus Perkmann et al., 2021; M. Perkmann, Tartari, McKelvey, Autio, Broström, et al., 2013). (Markus Perkmann et al., 2021; M. Perkmann & Walsh, 2009). På den anden side er der kritikere som påpeger, at interaktion med industrien kan have utilsigtede konsekvenser for akademisk forskning. Samarbejdet med industrien kan have indflydelse på både retning og fokus for den akademiske forskning, og kan medvirke til at relevante forskningsresultater hemmeligholdes på grund af kommercielle interesser fra industrielle samarbejdspartnere (Behrens & Gray, 2001; Florida, 1999; Krimsky, 1999; Slaughter & Leslie, 2001)

Denne afhandling undersøger det overordnede forskningsspørgsmål: hvordan påvirker industriens deltagelse i akademisk forskning inden for offentlig-privat samarbejdsprojekter forskningsproduktion og -formidling. Empirisk forankret i en dansk kontekst har afhandlingen til formål at forstå, hvordan retningen og formidlingen af akademisk forskning og gennemslagskraft heraf påvirkes inden for rammerne af offentlig-privat samarbejder. Gennem empiriske analyser af offentlig-private samarbejdsprojekter og publikationsdata samt en konceptualisering af publiceringsbeslutningen i offentlig-private projekter behandler afhandlingen fire underspørgsmål relateret til det generelle forskningsspørgsmål. Resultaterne danner et empirisk grundlag for at diskutere, hvorvidt det politiske fokus på at fremme interaktion mellem akademikere og virksomheder kan have utilsigtede eller negative konsekvenser for den videnskabelige videnproduktion og en diskussion af de potentielle mekanismer, der kan påvirke hvorvidt forskningsresultater producereret inden for offentlig-private samarbejdsprojekter projekter bliver offentliggjort.

Empirisk forskning har tidligere undersøgt de akademiske konsekvenser af at deltage i aktiviteter med industrien (Larsen, 2011; Markus Perkmann et al., 2021; M. Perkmann, Tartari, McKelvey, Autio, Brostrom, et al., 2013). Imidlertid undersøger disse studier ikke direkte, hvordan og i hvilken grad akademisk viden produceres inden for universitetsindustrielle projekter. På baggrund af tidligere undersøgelser af universitetsindustrielle projekter undersøger denne afhandling i en analyse af 117 offentlig-private samarbejder, i hvilket omfang projekter fører til publikationer afhængigt af dets formål og graden af virksomhedens involvering.

Forskere har hævdet, at interaktion med industrien kan få akademisk forskning til at bevæge sig mod mere kortsigtet, applikationsorienteret forskning på bekostning af grundlæggende videnskabelig forskning (Florida, 1999; Geuna, 2001). Der er dog meget lidt empirisk forskning som har undersøgt hvorvidt akademikere publicerer forskning i offentlig-private samarbejder af en anden karakter end det som produceres i deres akademiske samarbejder. Denne afhandling foretager en empirisk analyse af dette spørgsmål i en undersøgelse af publikationer produceret af 115 akademikere, der har deltaget i offentlig-private samarbejder.

Inspireret af den hovedsageligt politisk motiverede diskussion har tidligere undersøgelser forsøgt at vurdere gennemslagskraften af forskningsresultater som er produceret i offentlig-private samarbejder. Mens en håndfuld undersøgelser har fokuseret på gennemslagskraften af publikationer, der er samforfattet mellem virksomheder og akademikere (Lebeau, Laframboise, Lariviere, et al., 2008), er studierne stort set fokuseret på korrelationer og tager ikke fuldt ud hensyn til potentielle confounders. I denne afhandling undersøger jeg spørgsmålet om gennemslagskraft og samarbejde mellem universiteter og erhverv i en analyse af danske publikationer offentliggjort mellem 1995-2013 under hensyntagen til faktorer, der vides at korrelere med effekt, og således giver et mere effektivt skøn over forholdet mellem universitetet-industri samarbejde og gennemslagskraft.

De empiriske studier i denne afhandling indikerer tre generelle fund: 1) at akademisk forskning udført med industrien har tendens til at være perifer i forhold til, hvad akademikere generelt forfølger, 2) at projekttypen med hensyn til formål og grad af virksomhedens deltagelse er relateret til tilbøjeligheden til at offentliggøre forskning i videnskabelig litteratur og 3) at den forventede gennemslagskraft af publikationer, der er skrevet sammen med industrien, svarer til det forventede af lignende forskning, der er skrevet sammen med andre akademikere. Publikationer, der er skrevet sammen med udenlandske virksomheder med base i udlandet, har dog en højere forventet gennemslagskraft.

Min forskning viser, at den type projekter der forfølges sandsynligvis påvirker i hvilken grad viden bliver offentliggjort og typen af forskning der bedrives. Hvis det politiske formål med at fremme samarbejde mellem universiteter og virksomheder er at understøtte forskning, der gøres offentligt tilgængelig, så er projekter, der har en høj grad af virksomhedsdeltagelse eller er stærkt markedsorienteret, sandsynligvis projekter, der ikke burde få mest opmærksomhed. Disse typer projekter kan dog tilbyde andre fordele for samfundet, den akademiske verden og industrien. Endelig indebærer forskning med industrien sandsynligvis en bestemt type forskning, der er forskellig fra det som akademikere ellers ville forfølge; Derfor er en dybere forståelse af, hvad denne forskning er, og hvad den fører til, nødvendig for at forstå de forskningsmæssige konsekvenserne af incitamenter til sådanne interaktioner. Politisk er det vigtigt at erkende, at tilskyndelse til interaktion med industrien sandsynligvis betyder, at typen, formålet og indholdet af forskningen kan være forskellig fra den forskning, der udføres inden for den akademiske verden. Om forskellen er god, dårlig eller neutral er imidlertid et spørgsmål, der kræver mere forskning og et, der er stærkt normativt.

References

Ankrah, S., & Al-Tabbaa, O. (2015). Universities-industry collaboration: A systematic review. *Scandinavian Journal of Management, 31*(3), 387-408. doi:10.1016/j.scaman.2015.02.003

Banal-Estanol, A., Jofre-Bonet, M., & Lawson, C. (2015). The double-edged sword of industry collaboration: Evidence from engineering academics in the UK. *Research Policy, 44*(6), 1160-1175. doi:10.1016/j.respol.2015.02.006

Banal-Estanol, A., Macho-Stadler, I., & Perez-Castrillo, D. (2013). Research Output From University-Industry Collaborative Projects. *Economic Development Quarterly, 27*(1), 71-81. doi:10.1177/0891242412472535

Behrens, T. R., & Gray, D. O. (2001). Unintended consequences of cooperative research: impact of industry sponsorship on climate for academic freedom and other graduate student outcome. *Research Policy, 30*(2), 179-199. doi:10.1016/s0048-7333(99)00112-2

Bekendtgørelse af lov om opfindelser ved offentlige forskningsinstitutioner, 210, Ministeriet for Videnskab, Teknologi og Udvikling (1999).

Bloch, C. A., Jens Peter;, Ryan, Thomas Kjeldager; Schneider, Jesper Wiborg. (2017). *Collaboration in Research*. Retrieved from

Blumenthal, D., Campbell, E. G., Causino, N., & Louis, K. S. (1996). Participation of life science faculty in research relationships with industry. *New England Journal of Medicine, 335*(23), 1734-1739. doi:10.1056/NEJM199612053352305

Bornmann, L., & Daniel, H. D. (2008). What do citation counts measure? A review of studies on citing behavior. *Journal of Documentation, 64*(1), 45-80. doi:10.1108/00220410810844150

Bozeman, B., Fay, D., & Slade, C. P. (2013). Research collaboration in universities and academic entrepreneurship: the-state-of-the-art. *Journal of Technology Transfer, 38*(1), 1-67. doi:10.1007/s10961-012-9281-8

Callaert, J., Landoni, P., Van Looy, B., & Verganti, R. (2015). Scientific yield from collaboration with industry: The relevance of researchers' strategic approaches. *Research Policy, 44*(4), 990-998. doi:https://doi.org/10.1016/j.respol.2015.02.003

Cockburn, I. M., & Henderson, R. M. (1998). Absorptive Capacity, Coauthoring Behavior, and the Organization of Research in Drug Discovery. *The Journal of Industrial Economics, 46*(2), 157-182. doi:10.1111/1467-6451.00067

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2002). Links and Impacts: The Influence of Public Research on Industrial R&D. *Management Science, 48*(1), 1-23. doi:10.1287/mnsc.48.1.1.14273

Crespo, M., & Dridi, H. (2007). Intensification of university-industry relationships and its impact on academic research. *Higher Education, 54*(1), 61-84. doi:10.1007/s10734-006-9046-0

D'Este, P., & Patel, P. (2007). University-industry linkages in the UK: What are the factors underlying the variety of interactions with industry? *Research Policy, 36*(9), 1295-1313. doi:10.1016/j.respol.2007.05.002

D'Este, P., & Perkmann, M. (2011). Why do academics engage with industry? The entrepreneurial university and individual motivations. *Journal of Technology Transfer, 36*(3), 316-339. doi:10.1007/s10961-010-9153-z

D'Este, P., Tang, P., Mahdi, S., Neely, A., & Sanchez-Barrioluengo, M. (2013). The pursuit of academic excellence and business engagement: is it irreconcilable? *Scientometrics, 95*(2), 481-502. doi:10.1007/s11192-013-0955-2

Dasgupta, P., & David, P. A. (1994). TOWARD A NEW ECONOMICS OF SCIENCE. *Research Policy, 23*(5), 487-521.

De Fuentes, C., & Dutrénit, G. (2012). Best channels of academia-industry interaction for long-term benefit. *Research Policy, 41*(9), 1666-1682. doi:10.1016/j.respol.2012.03.026

Dutrenit, G., De Fuentes, C., & Torres, A. (2010). Channels of interaction between public research organisations and industry and their benefits: evidence from Mexico. *Science and Public Policy, 37*(7), 513-526. doi:10.3152/030234210x512025

Florida, R. (1999). The role of the university: Leveraging talent, not technology. *Issues in Science and Technology, 15*(4), 67-73.

Foray, D., & Lissoni, F. (2010). Chapter 6 - University Research and Public–Private Interaction. In H. H. Bronwyn & R. Nathan (Eds.), *Handbook of the Economics of Innovation* (Vol. Volume 1, pp. 275-314): North-Holland.

Foray, D., & Lissoni, F. (2010) University research and public-private interaction. In*: Vol. 1. Handbook of the Economics of Innovation* (pp. 275-314).

Foss, L., & Gibson, D. V. (2015). The entrepreneurial university: Case analysis and implications.

Franzoni, C., Scellato, G., & Stephan, P. (2011). Changing Incentives to Publish. *Science, 333*(6043), 702-703. doi:10.1126/science.1197286

Fudickar, R., Hottenrott, H., & Lawson, C. (2018). What's the price of academic consulting? Effects of public and private sector consulting on academic research. *Industrial and Corporate Change, 27*(4), 699-722. doi:10.1093/icc/dty007

Garcia, R., Araújo, V., Mascarini, S., Santos, E. G., & Costa, A. R. (2020). How long-term university-industry collaboration shapes the academic productivity of research groups. *Innovation, 22*(1), 56-70. doi:10.1080/14479338.2019.1632711

Garfield, E. (1963). Citation indexes in sociological and historical research. *American Documentation, 14*(4), 289-291.

Geuna, A. (2001). The changing rationale for European university research funding: Are there negative unintended consequences? *Journal of Economic Issues, 35*(3), 607-632.

Gibbons, M. (2000). Changing patterns of university - Industry relations. *Minerva, 38*(3), 352-361. doi:10.1023/a:1026559728608

Gläser, J., & Laudel, G. (2007). The social construction of bibliometric evaluations. In *The changing governance of the sciences* (pp. 101-123): Springer.
Godin, B., & Gingras, Y. (2000). Impact of collaborative research on academic science. *Science and Public Policy, 27*(1), 65-73. doi:10.3152/147154300781782147
Goldfarb, B. (2008). The effect of government contracting on academic research: Does the source of funding affect scientific output? *Research Policy, 37*(1), 41-58. doi:10.1016/j.respol.2007.07.011
Grimpe, C., & Hussinger, K. (2013). Formal and Informal Knowledge and Technology Transfer from Academia to Industry: Complementarity Effects and Innovation Performance. *Industry and Innovation, 20*(8), 683-700. doi:10.1080/13662716.2013.856620
Gulbrandsen, M., & Smeby, J. C. (2005). Industry funding and university professors' research performance. *Research Policy, 34*(6), 932-950. doi:10.1016/j.respol.2005.05.004
Hottenrott, H., & Lawson, C. (2017). Fishing for complementarities: Research grants and research productivity. *International Journal of Industrial Organization, 51*, 1-38. doi:10.1016/j.ijindorg.2016.12.004
Hottenrott, H., & Thorwarth, S. (2011). Industry Funding of University Research and Scientific Productivity. *Kyklos, 64*(4), 534-555. doi:10.1111/j.1467-6435.2011.00519.x
Katz, J. S., & Hicks, D. (1997). How much is a collaboration worth? A calibrated bibliometric model. *Scientometrics, 40*(3), 541-554. doi:10.1007/bf02459299
Krimsky, S. (1999). Perils of university-industry collaboration. *Issues in Science and Technology, 16*(1), 14-15.
Larsen, M. T. (2011). The implications of academic enterprise for public science: An overview of the empirical evidence. *Research Policy, 40*(1), 6-19. doi:10.1016/j.respol.2010.09.013
Lebeau, L. M., Laframboise, M. C., Lariviere, V., & Gingras, Y. (2008). The effect of university-industry collaboration on the scientific impact of publications: the Canadian case, 1980-2005. *Research Evaluation, 17*(3), 227-232. doi:10.3152/095820208x331685
Lundvall, B.-Å. (2016). National systems of innovation: towards a theory of innovation and interactive learning. *The Learning Economy and the Economics of Hope, 85*.
Manjarres-Henriquez, L., Gutierrez-Gracia, A., Carrion-Garcia, A., & Vega-Jurado, J. (2009). The Effects of University-Industry Relationships and Academic Research On Scientific Performance: Synergy or Substitution? *Research in Higher Education, 50*(8), 795-811. doi:10.1007/s11162-009-9142-y
Mansfield, E. (1991). ACADEMIC RESEARCH AND INDUSTRIAL-INNOVATION. *Research Policy, 20*(1), 1-12. doi:10.1016/0048-7333(91)90080-a
Mansfield, E. (1998). Academic research and industrial innovation: An update of empirical findings. *Research Policy, 26*(7-8), 773-776. doi:10.1016/s0048-7333(97)00043-7

Martin, B. R., & Irvine, J. (1983). Assessing basic research: Some partial indicators of scientific progress in radio astronomy. *Research Policy, 12*(2), 61-90. doi:https://doi.org/10.1016/0048-7333(83)90005-7
Martyn, J. (1964). BIBLIOGRAPHIC COUPLING. *Journal of Documentation, 20*(4), 236-236. doi:10.1108/eb026352
McCabe, A., Parker, R., & Cox, S. (2016). The ceiling to coproduction in university-industry research collaboration. *Higher Education Research & Development, 35*(3), 560-574. doi:10.1080/07294360.2015.1107888
Merton, R. K. (1969). BEHAVIOR PATTERNS OF SCIENTISTS. *American Scientist, 57*(1), 1-&.
Merton, R. K. (1988). The Matthew Effect in Science, II: Cumulative Advantage and the Symbolism of Intellectual Property. *Isis, 79*(4), 606-623.
Mitroff, I. I. (1974). Norms and Counter-Norms in a Select Group of the Apollo Moon Scientists: A Case Study of the Ambivalence of Scientists. *American Sociological Review, 39*(4), 579-595. doi:10.2307/2094423
Mohan-Ram, V. (2001). Patent first, publish later: how not to ruin your chances of winning a patent. *Science*.
Mora-Valentin, E. M., Montoro-Sanchez, A., & Guerras-Martin, L. A. (2004). Determining factors in the success of R&D cooperative agreements between firms and research organizations. *Research Policy, 33*(1), 17-40. doi:10.1016/s0048-7333(03)00087-8
Mowery, D. C. (1998). Collaborative R & D: How effective is it? *Issues in Science and Technology, 15*(1), 37-44.
Mowery, D. C., & Sampat, B. N. (2004). The Bayh-Dole Act of 1980 and university-industry technology transfer: A model for other OECD governments? *Journal of Technology Transfer, 30*(1-2), 115-127. doi:10.1007/s10961-004-4361-z
Nelson, R. R. (2004). The market economy, and the scientific commons. *Research Policy, 33*(3), 455-471. doi:10.1016/j.respol.2003.09.008
OECD. (2013). *Commercialising Public Research*: OECD Publishing.
Perkmann, M., Salandra, R., Tartari, V., McKelvey, M., & Hughes, A. (2021). Academic engagement: A review of the literature 2011-2019. *Research Policy, 50*(1), 104114. doi:https://doi.org/10.1016/j.respol.2020.104114
Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Brostrom, A., D'Este, P., . . . Sobrero, M. (2013). Academic engagement and commercialisation: A review of the literature on university-industry relations. *Research Policy, 42*(2), 423-442. doi:10.1016/j.respol.2012.09.007
Perkmann, M., & Walsh, K. (2007). University-industry relationships and open innovation: Towards a research agenda. *International Journal of Management Reviews, 9*(4), 259-280. doi:10.1111/j.1468-2370.2007.00225.x
Perkmann, M., & Walsh, K. (2009). The two faces of collaboration: impacts of university-industry relations on public research. *Industrial and Corporate Change, 18*(6), 1033-1065. doi:10.1093/icc/dtp015
Rentocchini, F., D'Este, P., Manjarrés-Henríquez, L., & Grimaldi, R. (2014). The relationship between academic consulting and research performance: Evidence

from five Spanish universities. *International Journal of Industrial Organization, 32*, 70-83. doi:https://doi.org/10.1016/j.ijindorg.2013.11.001
Rosenberg, N. (1990). WHY DO FIRMS DO BASIC RESEARCH WITH THEIR OWN MONEY. *Research Policy, 19*(2), 165-174. doi:10.1016/0048-7333(90)90046-9
Salter, A. J., & Martin, B. R. (2001). The economic benefits of publicly funded basic research: a critical review. *Research Policy, 30*(3), 509-532. doi:10.1016/s0048-7333(00)00091-3
Schaeffer, P. R., Ruffoni, J., & Puffal, D. (2015). Reasons, benefits and difficulties of the university-industry interaction. *Revista Brasileira De Inovacao, 14*(1), 105-134.
Schartinger, D., Rammer, C., Fischer, M. M., & Fröhlich, J. (2002). Knowledge interactions between universities and industry in Austria: Sectoral patterns and determinants. *Research Policy, 31*(3), 303-328.
Slaughter, S., & Leslie, L. L. (2001). Expanding and Elaborating the Concept of Academic Capitalism. *Organization, 8*(2), 154-161. doi:10.1177/1350508401082003
Stephan, P. E. (1996). The economics of science. *Journal of Economic Literature, 34*(3), 1199-1235.
Stephan, P. E. (2004). Robert K. Merton's perspective on priority and the provision of the public good knowledge. *Scientometrics, 60*(1), 81-87. doi:10.1023/b:scie.0000027311.17226.70
Stephan, P. E. (2008). Science and the university: Challenges for future research. *Cesifo Economic Studies, 54*(2), 313-324. doi:10.1093/cesifo/ifn014
Stephan, P. E. (2010). Chapter 5 - The Economics of Science. In H. H. Bronwyn & R. Nathan (Eds.), *Handbook of the Economics of Innovation* (Vol. Volume 1, pp. 217-273): North-Holland.
Stokes. (1997). Pasteur's_Quadrant.
Styrelsen for Forskning og Innovation, A. o. E. (2015). *Kommercialisering of forskningsresultater 2014 og kortlægning af videnssamspil i bredere perspektiv*. Retrieved from Copenhagen K: https://ufm.dk/publikationer/2015/kommercialisering-af-forskningsresultater-2014
Styrelsen for Forskning og Innovation, A. o. E. (2016). *Viden til Vækst; offentlig of privat samspil om forskning*. Retrieved from Copenhagen K: https://ufm.dk/publikationer/2016/filer/viden-til-vaekst-2016-docx.pdf
Tal om danske universiteter 2019. (2020). Retrieved from Copenhagen K: https://dkuni.dk/wp-content/uploads/2020/05/du_tal_om_danske_universiteter_2019.pdf
Tartari, V., & Breschi, S. (2012). Set them free: scientists' evaluations of the benefits and costs of university-industry research collaboration. *Industrial and Corporate Change, 21*(5), 1117-1147. doi:10.1093/icc/dts004
Van Looy, B., Callaert, J., & Debackere, K. (2006). Publication and patent behavior of academic researchers: Conflicting, reinforcing or merely co-existing?

Research Policy, 35(4), 596-608. doi:https://doi.org/10.1016/j.respol.2006.02.003

Van Raan, A. (1996). Advanced bibliometric methods as quantitative core of peer review based evaluation and foresight exercises. *Scientometrics, 36*(3), 397-420.

Van Raan, A. (1998). The influence of international collaboration on the impact of research results: Some simple mathematical considerations concerning the role of self-citations. *Scientometrics, 42*(3), 423-428.

Waltman, L., & van Eck, N. (2013). Source normalized indicators of citation impact: an overview of different approaches and an empirical comparison. *Scientometrics, 96*(3), 699-716. doi:10.1007/s11192-012-0913-4

Webster, A. (1994). International evaluation of academic-industry relations: Contexts and analysis. *Science and Public Policy, 21*(2), 72-78. doi:10.1093/spp/21.2.72

Aagaard, K. M., Niels; Degn, Lise; Sorensen, Mads P; Bloch, Carter; Ravn, Tine; Hansen, Hanne Foss. (2012). *Dansk forskningspolitik secrecy is the active or passive behaviour of withholding and protecting knowledge. efter årtusindskiftet* (K. M. Aagaard, Niels Ed.). Gylling, Denmark: Aarhus Universitetsforlag.