What lies beneath the surface?

A review of academic and policy studies on collaboration between public research and private firms

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INTRODUCTION

The purpose of the review described in this report was to gather and synthesize academic and policy-oriented literature on collaboration between public research institutions and private firms. The aim was to identify and communicate "state-of-the-art" knowledge about mechanisms, motivations, and barriers for collaboration between public science and industry.

The review was commissioned by the Danish Council for Research and Innovation Policy and undertaken by DEA, a Danish non-profit think tank on education, science and innovation policy. The work behind the report was financed jointly by the Danish Council for Research and Innovation Policy and DEA.

The subject area of this review is massive and has been addressed in numerous scientific publications, policy analyses, evaluations and other written material. It was beyond the scope of this study to undertake a comprehensive review of all this material or to cover all relevant themes or literature in equal depth. Instead, we have sought to provide an overview of key studies and themes, and to draw out the main findings and implications for policymakers and university managers looking to promote and support university-industry collaboration.

The review builds on a wide search for academic and policy literature, primarily from the past ten years, but supplemented with relevant earlier texts, particularly from the academic literature. In the search for literature, emphasis has been placed on peer reviewed academic publications, supplemented with some of the most comprehensive or relevant policy-oriented publications on the topic.

In view of the limited time period available for completion of the review, we have drawn on prior reviews undertaken by the author of this report. These include academic publications as well as non-academic studies. For a list of this prior work, please see the next page.

Although the themes and issues covered in the review are global, the primary target group of the review are the members of the Danish Council for Research and Innovation Policy and policymakers and other relevant stakeholders in Denmark. This is reflected in the selection of literature included in the review, and in the discussion of key findings from this literature. For example, certain sections are dedicated to a presentation of recent findings from Denmark.

We acknowledge that a substantial part of the interaction that universities are involved in is with the public sector, for instance government agencies and ministries, regional and local authorities, public hospitals and schools, childcare institutions and utility companies. This review, however, is focused on the interplay between public research and the *private* sector.

We also recognize that public research organizations include a variety of institutions, including universities, university hospitals and government research institutions. This review focuses primarily on universities, which dominate the public research sector in Denmark, and which are most heavily studied in the literature. Whenever possible, we have included studies that examine other public research organizations.

Prior work by the author that this review draws on

The review presented in this report builds on elements of previous reviews undertaken by the author in connection with the following publications:

Davis, L., Larsen, M.T., Lotz, P., 2011. Scientists' perspectives concerning the effects of university patenting on the conduct of academic research in the life sciences. Journal of Technology Transfer 36, 14-37.

DEA, 2013. Fra forskning til faktura: Hvad kan vi lære af ti års forsøg på at tjene penge på forskning?

DEA, 2013. "Dødens gab" mellem opfindelser og innovationer: Et overblik over forskning i hvorfor nogle innovationsprojekter mislykkes. Et review udarbejdet for Erhvervsstyrelsen.

DEA, 2014. University researchers' collaboration with industry and the public sector: A survey of university researchers in Denmark.

DEA, 2014. Debatoplæg: Dansk forskning anno 2030: Er vi stadig i verdensklasse?

DEA & DI, 2014. Fra forskning til innovation: Om virksomheders brug af erhvervsrettede forsknings- og innovationsordninger.

DEA, 2015. Debatoplæg: Hvordan får vi mere samfundsnytte ud af vores forskningsinvesteringer?

Mark, M., Jensen, R.L., Norn, M.T., 2014. Estimating the economic effects of university-industry collaboration. International Journal of Technology Transfer and Commercialisation 13, 80-106.

Larsen, M.T., 2007. Academic Enterprise: A New Mission for Universities or a Contradiction in Terms? Copenhagen Business School PhD Series, Samfundslitteratur, Copenhagen.

Larsen, M.T., 2011. The implications of academic enterprise for public science: An overview of the empirical evidence. Research Policy 40, 6-19.

The full list of references cited in the review is available at the end of this report.

EXECUTIVE SUMMARY (IN DANISH)

Universiteter forventes i stigende omfang ikke blot at levere forskning og højtuddannede dimittender, men også at yde et mere direkte bidrag til økonomisk vækst, primært gennem samarbejde med erhvervslivet og en aktiv indsats for at fremme kommercialiseringen af forskning. Det positive afkast af investeringer i offentlig forskning er veldokumenteret og konservativt estimeret til mellem 20 og 40 procent. Gevinsten for virksomheder, som indgår i samarbejde med universiteter, er også veldokumenteret, i form af både øget innovation og økonomisk performance.

Samarbejde mellem universiteter og erhvervslivet er ikke et nyt fænomen, men er i de seneste årtier vokset i både volumen og typer af samarbejdskanaler.

Litteraturen påviser en stærk sammenhæng mellem forskning af høj kvalitet og samarbejde med erhvervslivet. Det indikerer, at uafhængig forskning af høj kvalitet er en forudsætning for effektivt samarbejde med erhvervslivet, og understreger betydningen af støtte til langsigtet, excellent forskning.

Politikere har fokuseret for snævert på patenter, spinout-virksomheder og formelt FoU-samarbejde som kanaler for nyttiggørelse af forskning. Dette har skygget for andre kanaler – fx rekvireret forskning, konsulentydelser, uformelt samarbejde og jobmobilitet – som kan være effektive kanaler for overførsel af tavs viden og teknologi til erhvervslivet. Der er desuden væsentlige indbyrdes afhængigheder mellem typer af samarbejdskanaler, hvorfor det fx ikke giver mening at forsøge at øge fx antallet af patenter uden samtidig at stimulere kanaler for formelt eller uformelt samarbejde, samt de bagvedliggende personlige netværk.

Politikeres (og nogle universiteters) håb om, at teknologioverførsel ville generere økonomisk overskud for universiteter er blevet gjort til skamme. Kun en håndfuld af verdens universiteter lykkes med at tjene penge på deres patenter. Indtægter kan desuden tilskrives ganske få, men exceptionelt lukrative patenter. Selv de universiteter, som tjener mest, kæmper for at tjene et overskud: blandt de 20 amerikanske universiteter, som tjener mest i licensindtægter, formår kun fem at høste et overskud. For de fleste universiteter bør teknologioverførsel derfor ses ikke som en indtægtskilde, men snarere som en investering i videnspredning til erhvervslivet.

Spinouts er ikke altid en effektiv kanal for kommercialisering af forskning. De fleste spinouts fra universiteter forbliver små og vokser mindre end andre højteknologiske virksomheder. Forskere har dog argumenteret, at profit og vækst ikke nødvendigvis er de eneste succeskriterier for universitetsspinouts: på grund af deres forskningsbaserede natur kan selv tabsgivende virksomheder stadig yde et betydeligt bidrag ved at oversætte banebrydende forskning og stille den til rådighed for andre virksomheder.

Kvantitative indikatorer har forstærket det enfoldige fokus på forskningsresultater, som er nemt målbare. Kvantitative indikatorer for videnudveksling kan give universiteter uhensigtsmæssige incitamenter til at levere målbare resultater (fx patenter), og reelt straffe mere værdiskabende tiltag for at fremme den erhvervsmæssige nyttiggørelse af forskning (fx gennem uformelt samarbejde eller konsulentydelser). Brugen af kvantitative indikatorer bør derfor kvalificeres gennem kvalitativ indsigt i videnudveksling.

Erhvervsorientering og god forskning går hånd i hånd: forskere, som indgår i samarbejde med den private sektor, er tilbøjelige til også at udvise stærk videnskabelig performance, målt på antallet og gennemslagskraften af deres videnskabelige publikationer. Forholdet mellem erhvervsorientering og videnskabelig performance er dog kurvelineært; det indikerer, at forskere kan arbejde *for* tæt sammen med erhvervslivet. Derudover er årsagssammenhængen uklar: er samarbejdende forskere bedre forskere, *fordi* de samarbejder med erhvervslivet, eller er de bedre til at samarbejde, *fordi* de er bedre forskere?

Forsinkelser og begrænsninger på adgang til offentlige forskningsresultater som følge af samarbejde med erhvervslivet lader ikke til at udgøre et betydeligt eller udbredt problem. Dog peger litteraturen på tilfælde, hvor adgang forsinkes eller begrænses. Der er brug for mere viden om, hvornår og hvorfor dette sker, samt om problemets omfang og konsekvenser.

Bedre indsigt i forskeres prioriteringer er væsentlig for at opnå øget universitets-erhvervssamarbejde, fordi samarbejde i sidste ende afhænger af, hvordan den enkelte forsker beslutter at prioritere sin tid; denne beslutning afhænger i høj grad af forskerens opfattelse af omkostninger og gevinster forbundet med samarbejde med erhvervslivet. Dette kalder på større opmærksomhed på individuelle forskeres opfattelser af barrierer og incitamenter for samarbejde. Derudover påvirkes forskeres opfattelse af erhvervssamarbejde bland andet af deres videnskabelige performance, anciennitet, alder og motivation for at indgå i erhvervssamarbejde. Det er derfor vigtigt at overveje, hvordan nye tiltag for at fremme samarbejde med erhvervslivet kan forventes at påvirke forskellige undergrupper af forskere på forskellig vis.

Forskere, som indgår i samarbejde med erhvervslivet, er typisk ikke motiveret af personlig økonomisk gevinst, men af muligheden for at tilgå værdifulde input til deres forskning og undervisning, fx forskningsmidler, ideer til nye forskningsprojekter eller adgang til materialer og udstyr. En vigtig nøgle til at motivere flere forskere til at indgå i samarbejde med erhvervslivet er derfor at hjælpe dem med at realisere fordele for deres forskning og undervisning. Væsentlige barrierer for samarbejde med erhvervslivet er manglende prioritering/anerkendelse fra ledelsen samt forskellige tidshorisonter og målsætninger i forskningsverdenen og erhvervslivet; disse barrierer bør derfor adresseres, hvad enten de er reelle eller oplevede.

FoU-samarbejde kan ende i skuffede forventninger eller decideret fiasko. Faktorer, som øger chancen for succes i samarbejdsprojekter, er: tidligere samarbejdserfaring, anvendelse af flere forskellige kanaler for samarbejde mellem de samme partnere, opbygning af tillid mellem partnere, øget FoU-intensitet (hos erhvervspartnere), øget forskningskvalitet (hos universitetspartnere), geografisk nærhed og professionel (snarere end ad hoc) ledelse af samarbejdet.

Universiteter forventes ofte at yde et væsentligt bidrag til vækst i regionale/lokale innovationssystemer, selv om der er relativt lidt dokumentation for, at universiteter er effektive i at etablere sådanne systemer. Som minimum bør politikere undgå generiske tilgange og i stedet skræddersy deres politik i lyset af særlige ressourcer og specifikke udfordringer for det pågældende universitet og i det pågældende område. Forskning peger også på fordelene ved en mere selektiv tilgang, der tillader universiteter at fokusere deres ressourcer i lokalområdet på virksomheder, som *både* har en tilstrækkelig intern FoU-kapacitet og absorptionskapacitet og tilstrækkeligt specialiserede FoU-behov til at kunne indgå i et værdiskabende samarbejde med universitetsforskere.

Den offentlige forsknings bidrag til økonomisk vækst afhænger også af virksomheders vilje og evne til at omsætte forskning til nye produkter og processer. Offentlig forskning er blot én af mange kilder til innovation i erhvervslivet, og en som meget få virksomheder trækker direkte på. Derudover er private investeringer i FoU stagneret siden 2010. At stimulere yderligere private investeringer kræver enten øget økonomisk råderum i virksomheder eller offentlige bevillinger, som kan geare deres interne FoU-midler.

Virker offentlige ordninger for FoU-samarbejde mellem virksomheder og universiteter? Der er ingen klar dokumentation for, at offentlige FoU-subsidier skulle fortrænge private investeringer; til gengæld finder forskningen heller ikke overbevisende dokumentation for, at offentlige FoU-ordninger har betydelig additionalitet. Hvorfor viser analyser af effekterne af offentlige FoU-ordninger ikke bedre resultater? En del af forklaringen kan ligge i den høje grad af variation inden for de aktiviteter, som disse ordninger støtter; projekter er ikke lige succesfulde, og mange projekter er ganske enkelt ikke så godt tilrettelagt eller styret, som de kunne være. Forskning viser desuden, at subsidier til "forskning" har større sandsynlighed for at stimulere private FoU-investeringer, mens subsidier til "udvikling" ser ud til at substituere privat investering, hvilket tyder på, at offentlig støtte bør fokuseres til forsknings- snarere end udviklingsprojekter.

"Proof of concept"-funding: det manglende led mellem forskning og innovation? Litteraturen peger på et behov for at vurdere, om der i dag findes tilstrækkelige midler til at bringe lovende, universitetsopfindelser sikkert over "Dødens Gab", dvs. til et punkt, hvor de er attraktive for private investorer.

Litteraturstudiet peger på behov for mindre fokus på kvantitet og mere fokus på kvalitet i den videnudveksling, der finder sted mellem universiteter og virksomheder. Det understreger også behovet for fleksible tiltag, som i højere grad end i dag tager højde for variation på tværs af geografiske områder, videnskabelige hovedområder, og endda individuelle forskere. Sidst, men ikke mindst forudsætter bedre politikudvikling mere systematiske, bedre evalueringer.

EXECUTIVE SUMMARY (IN ENGLISH)

Universities are increasingly expected not just to undertake and disseminate fundamental research and churn out highly skilled graduates, but also to contribute more directly to economic growth, notably through direct collaboration with industry and active efforts to commercialize academic research results. The positive impact of public investments in university research is well-documented, with conservative estimates of the return on such investments ranging from 20 to 40 percent. The payoff for firms who engage directly in collaboration with universities is similarly well-documented, both in the form of increased innovation and improved financial performance.

University-industry collaboration is not a new phenomenon, but has in recent decades increased in both *volume* and the *variety* of types of collaboration.

The literature points to a strong relationship between high quality research and collaboration with industry, indicating that high-quality, independent academic research is a prerequisite for effective university-industry collaboration and underlining the importance of long-term support for excellent academic research.

Science policy has focused too narrowly on patents, university spinouts, and formal R&D collaboration as mechanisms for commercial exploitation of science. Other mechanisms – e.g. contract research and consulting, informal collaboration, employee exchanges and job mobility – have been overshadowed, but are often more valuable in terms of enabling a productive exchange of tacit knowledge and technology between universities and industry. There are also significant interdependencies between mechanisms, implying that it does not make sense to simply push for e.g. more university patents: boosting university-industry interaction requires stimulating several mechanisms and the underlying personal ties.

Policymakers' (and some universities') hopes that technology transfer would generate financial profit for universities have, by and large, been crushed. Only a handful of universities in the world succeed in making money from their patents. This money can moreover be traced to a very small number of exceptionally lucrative patents; most patents make no money. Even the universities that receive the most licensing income struggle to make a profit: among the 20 top-earning universities in the US, only five make a profit. For most universities, costs of technology transfer should therefore be seen not as a source of income, but rather as *investments* in research dissemination; this has important implications for how resources for technology transfer activities are prioritized and used.

Spinouts are not always an effective means of commercializing research. Moreover, most academic spinouts remain small and grow less than other high tech companies. However, it's been argued that profit and growth may not be the only success parameters for university spinouts: by virtue of their research-based nature, even loss-making firms may still make a significant contribution by translating cutting-edge research and making it available to other firms.

Quantitative indicators have reinforced the single-minded emphasis on easily measurable outputs. Quantitative indicators for knowledge exchange can give universities undesirable incentives to deliver measurable outputs (e.g. patents), while potentially penalizing productive efforts to bring academic research to commercial use (e.g. through informal collaboration or consulting). Use of quantitative indicators should thus be informed by qualitative insight.

Industry orientation and good science go hand in hand: researchers who engage with the private sector are likely to show strong scientific performance in terms of high productivity and scientific impact. However, the relationship between industry orientation and scientific performance is curvilinear, suggesting that it is possible for researchers to work *too* closely with industry. Moreover, the direction of causality is unclear: are collaborating researchers better scientific performers *because* they engage with industry, or are they better at engaging with industry *because* they are excellent researchers?

Delays and restrictions on access to public research as a result of collaboration with industry do not appear to be a widespread or large-scale problem. However, there *do* appear to be instances where delays or restrictions occur. More study is needed to determine when and why they occur, as well as their severity and wider consequences.

Better understanding of individual researchers' attitudes is key to increasing university-industry collaboration, because such collaboration ultimately depends on individual researchers' decisions about how to prioritize their time, which in turn is largely based on the perceived costs and benefits of collaborating with industry. More attention ought therefore to be paid to obstacles and incentives as perceived by the individual researcher. Moreover, researchers' perceptions differ based on e.g. their scientific performance, academic position, age and motivations to engage with industry, suggesting the need to consider how new policy initiatives are likely to impact different subsets of researchers in different ways.

Researchers who collaborate with industry do so not for financial gain but to reap valuable inputs for their research and teaching, e.g. research funding, ideas for new research paths, or access to materials or equipment. An important means to motivate more researchers to engage in collaboration is therefore to help them realize benefits for their research and teaching activities. Key barriers to collaboration with industry are lack of prioritization/reward from university management, and conflicting timeframes and goals in academia and industry; these barriers, whether real or perceived, should be addressed.

R&D collaborations often fail or fall short of expectations. Factors that may increase the chance of success in university-industry collaborations include: prior collaboration experience, employing multiple mechanisms for collaboration between parties, building trust among partners, higher R&D intensity (in industry partners), higher research quality (in university partners), geographical proximity and professional (rather than ad hoc) management of the collaboration.

Universities are often expected to play a leading role in driving growth in regional/local innovation systems, even though there is little evidence to support that universities are effective in creating such systems. At minimum, policymakers should avoid generic approaches and instead tailor policies to the particular resources and challenges of the university and the innovation system in question. Research also calls for a more selective approach, allowing universities to focus their resources on local/regional firms that have sufficient R&D intensity and absorptive capacity *and* the specialized R&D needs necessary to engage productively with academic researchers.

The contribution of public science to economic growth also depends on firms' willingness and ability to translate that science into new products and processes. Public science is but one of many inputs to private innovation, and one that very few firms tap into. In addition, private investments in R&D in Denmark have stagnated since 2010. Stimulating private investments requires either greater financial slack within the firms or providing public R&D grants that can supplement firms' in-house R&D funding.

Do public grants for R&D collaboration, e.g. between universities and firms, work? There is no conclusive evidence that public R&D subsidies crowd out private investment, yet studies also fail to find evidence of substantial additionality. Why aren't studies of public grants for collaborative R&D finding better results? Part of the explanation might lie in the substantial variation in the performance of projects supported by such grants; many projects simply aren't as well designed or managed as they could or should be. Moreover, research shows that "research" subsidies are likely to stimulate R&D spending by firms, while "development" subsidies appear to *substitute* such spending, suggesting that public programs should focus on research rather than development projects in order to stimulate more R&D.

"Proof of concept" funding: the missing link in translating science to innovation? Studies suggest the need to assess whether there is at present sufficient funding available to bring promising, early-stage university inventions across the "Valley of Death" to a point where they become attractive to private investors.

All in all, the review of the literature suggests the need for an increased focus on quality, rather than quantity, in university-industry knowledge exchange. It also points to the need for flexible rather than "one size fits all" policies in order to accommodate variations across geographical regions, scientific disciplines, universities and even individual researchers into account. Finally, better policymaking requires more systematic, higher-quality evaluations.

Policy makers eager to boost the contribution of academic research to innovation and growth all too often look for quick "success stories" trying to emulate … US success stories, like Silicon Valley, which have taken a long time to develop. Most policies lack a systemic, long term perspective needed to develop a triple helix eco-system. Furthermore, the target of the policies is usually mostly narrowly focused on commercialization of university technologies, rather than [a] broader contribution to economic development. They all too often focus their target on patenting, licensing and spin-offs ... Although [licensing and spinoffs] receive most attention, they are however most probably among the least important gateways. Student spin-offs, graduate mobility and other more informal collaborative modes with industry are more effective to impact the innovative performance of industry. There is no one-size-fits-all approach to stimulating the contribution of academic research to (regional) economic development that so many governments have been pursuing. The results from the still developing literature calls for a broader view of the role of universities and public research organisations – as creators, receptors, and interpreters of innovation and ideas; as sources of human capital formation; and as key components of social infrastructure and social capital. … To progress, policy makers should be more serious about evaluating their instruments and support more systematic data collection on the various pathways for universities' contribution.

Veugelers (2014, p. 28)

EXTENDED SUMMARY

This extended summary presents key themes and conclusions from the literature review as well as the author's reflections on possible policy implications of these conclusions. References to the literature are available in the report.

Policymakers are pushing for faster, greater returns on public investments in science

Since the 1970s, policymakers around the world have sought to boost both the extent as well as the effectiveness of university-industry collaboration in order to stimulate innovation that can drive national and regional economic growth and competitiveness. Universities are seen as catalysts for growth that provide talent, knowledge and inventions to the so-called knowledge-based economy. Industry is then seen as the engine that transforms research into marketable products, thus powering the economy. But the interplay between public research organizations and private firms is often suboptimal or even entirely lacking, leaving room for public intervention.

A "third mission" for universities

Universities' main contribution to society lies in the education of skilled graduates and the wide dissemination of research knowledge, techniques and instruments. This generates substantial value to society; according to reviews, a conservative estimate of the return on investment in public science lies between 20 and 40 percent. However, the effects of university research are mostly indirect, long-term and difficult to measure. Meanwhile, politicians are under pressure from intensified global competition and constraints on public funding; they therefore call for measurable results from public investments in science than can legitimize these investments while boosting economic growth and competitiveness.

Universities are thus expected to deliver more "relevant" research with a direct impact on innovation and growth, also in the short-term. This has been referred to as a "third mission" for universities, alongside their traditional missions of providing research-based knowledge and skilled graduates. This "third mission" refers to an obligation to actively promote the dissemination and commercial exploitation of university research, notably through direct collaboration with firms and by patenting university inventions and licensing or selling the intellectual property (IP) rights to those inventions to established firms or new "spinout" firms.

Something old, something new

Expectations for universities to engage with their surrounding community are not a new phenomenon, but rather represent a shift back to older (pre-WWII) models for the "social contract" between societies and universities. Universities in both Europe and the US have a centuries old tradition of serving the needs of the private sector and society in return for receiving public funding. What *has* changed in recent decades, however, is the institutionalization of university-industry collaboration in academia. Moreover, this collaboration is increasing in both volume and variety in regards to the types of collaboration mechanisms used. Also new is the focus on universities' role in actively promoting and even pursuing the commercial exploitation of research results, particularly through patenting and the formation of spinout companies.

Technology transfer is an investment in the dissemination of science – not a cash cow

Policies to promote university patenting, licensing and spinouts have been inspired at least partly by anecdotal evidence of successful research commercialization by a handful of US universities, and by hopes that these activities might supply universities with additional income in a time of public budget constraints and rising costs of research. These hopes have, by and large, been disappointed.

A review of international studies confirms that very few universities succeed in making money from their patents. For example, studies have shown that the top 10 percent universities as indicated by licensing income account for 85 percent of all university licensing income in Europe (European Commission 2012) and 70 percent of all university licensing income in the US (Valdivia 2013). Moreover, even among the 20 top-earning universities in the US, only 5 generate enough income to cover the costs of their technology transfer activities (ibid.).

Moreover, the universities who *do* succeed in making money from their inventions owe their earnings to a very small number of exceptionally lucrative patents; most patents generate little or no licensing income. Finally, the literature shows that the universities who make the most money from their technology transfer activities are also those that receive the most public funding, hinting at a positive relationship between successful transfer on the one hand and research quality and resources on the other.

Similarly, the Danish technology transfer system, which was designed to be financially self-sustaining, is not likely to generate a profit and will not even reach the breakeven point in most universities. This suggests that costs involved in technology transfer should be seen as investments in research dissemination and application rather than as a potential source of income for the universities; this has important implications for how resources for technology transfer activities are prioritized and used.

Spinouts are not always an effective means of commercializing research – and have so far yielded disappointing aggregate results

Relatively little is known about spinouts from Danish universities, except that they have increased significantly in numbers since the early 2000s. There is limited systematic insight into the nature, funding, strategic choices or long-term performance of the spinouts that have been established. Similarly, there has been little independent evaluation of efforts to boost the number or quality of spinouts in recent years.

Spinouts are seen as suitable and effective vehicles for advancing the exploitation of research and are most prominent in science-based and high-tech sectors. But the suitability of spinouts as a vehicle for commercialization depends, among other things, on the effectiveness of patents in protecting the invention and building a strong patent portfolio, the importance of complementary assets for the exploitation of the invention, the age of the industry, the degree of market segmentation and the average firm size. Also, spinouts involve a greater commitment from the inventor researcher than licensing: the transition is greater (as inventors, researchers will often play a role in the spinout, at least initially), and the stakes higher. Yet keeping the inventors involved in a new venture has been shown to be crucial in ensuring an effective transfer of technology to the spinout. However, most researchers are neither particularly interested in or suited for entrepreneurship, and usually lack the commercial network, experience and skills to engage effectively in entrepreneurship.

Despite the focus on and increased volume of academic spinouts, their financial results have, so far, been modest, and their impact on economic growth limited, not just in Denmark, but worldwide. In fact, most academic spinouts remain small and grow less than other high tech companies. This may indicate lower average quality; in fact, it has been suggested that business cases for academic spinouts are not subject to the same requirements as business ideas in highly competitive entrepreneurial environments with better abilities to assess commercial potential, and that close ties to the parent university may even keep ventures “alive” for longer than warranted (though such ties can also be very beneficial to spinout firms). However, scholars have argued that even if university spinouts are not high-growth firms, by virtue of their research-based and thus cutting-edge nature, they may still make a significant contribution to the innovativeness of their customers or be transferred to and exploited commercially by other firms, e.g. through an acquisition. Thus, profit and growth may not be the only success parameters for university spinouts.

Finally, the survey of the literature shows that academic spinouts are characterized by a high degree of heterogeneity in terms of e.g. their resources, their business models and the institutional settings from which they emerge. Moreover, there is not one "recipe" for creating spinouts but rather several possible approaches. As one study puts it, "universities can adopt different strategies yet achieve similar results" (Berbegal-Mirabent et al. 2015, p. 2277).

Patents and spinouts are just "the tip of the iceberg"[1] – and have obscured other, more important mechanisms for interaction

Policymakers have focused heavily on patents and spinouts as indicators of universities' contribution to innovation and growth. Yet the evidence shows that these are but two of many channels through which universities interact with industry and create value for society. They have become policy darlings because they are relatively easy to measure and associated with tangible economic results. They have become almost synonymous with university impact on industry and society, even though that impact is primarily generated through other, less visible mechanisms, e.g. collaborative R&D, contract research, consulting, staff mobility, collaboration on training of students or staff, informal collaboration etc. For example, the most common mechanisms for interaction with industry among Danish researchers are joint research projects, collaboration on teaching of students, training of young researchers, and providing advice on an informal basis.

The literature also indicates that mechanisms for collaboration cannot be viewed separately. For instance, commercialization will often be an outcome of or follow-on activity to actual collaboration between university researchers and industry, rather than a stand-alone activity. Commercialization may also be accompanied by collaboration, e.g. when spinouts work with the research labs that they originated from, when the aim is to transfer tacit knowledge to or explore new research avenues with companies that have licensed an invention. Moreover, the literature shows that good university-industry ties are often long-term and make use of multiple mechanisms for knowledge exchange; they are usually built on (and reinforce) strong personal ties between individuals.

Policies to stimulate university-industry knowledge exchanges should take into account possible interdependencies between mechanisms. For instance, IPR licensing may lead to sponsored research, or consulting, contract research and collaboration on teaching may open the door to collaborative R&D. In particular, the literature indicates that more attention should be paid to contract research and consulting, which can help build trust among collaborators and pave the way for new collaborative ventures, particularly in the social sciences and the humanities where formal R&D collaboration is less common. The survey of the literature also suggests that informal mechanisms such as personnel exchanges and other form of staff mobility can play an important role in strengthening personal ties, building trust, and transferring tacit knowledge. This indicates that such mechanisms for collaboration and knowledge exchange should be encouraged and supported as a means of promoting stronger and more valuable ties between academia and industry.

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[1] Credit for this metaphor goes to Salter (2002) and Perkmann & Salter (2012).

Mechanisms for direct interaction between universities and firms

Overall, the evidence indicates that it is counterproductive to seek to increase specific mechanisms for university-industry knowledge exchange without taking interdependencies with other mechanisms into account. Policies aimed at promoting long-term collaborative relationships between academia and industry should, according to insights from the literature, recognize the importance of using multiple mechanisms for collaboration and strong personal ties, rather than promote selected mechanisms, e.g. patenting and spinouts. Moreover, it is important to recognize that the most effective set of mechanisms for university-industry collaboration will vary between disciplines and industry sectors, and between researchers and firms.

What you measure is what you get: when proxies become de facto goals[2]

The use of quantitative indicators to measure knowledge exchange has reinforced the rather single-minded policy emphasis on patents, licensing deals, collaborative agreements, spinouts etc. Such indicators may for instance give universities incentives to focus on increasing the number of patents granted rather than on getting higher quality disclosures through early dialogue with researchers (which may actually decrease the number of disclosures), or to pursue licensing deals or spinouts in cases where other mechanisms for collaboration might offer a more suitable path to commercialization and even in the long-term generate more income for the university through e.g. contract research, consulting fees or sponsored research.

When quantitative indicators are not tempered by informed, qualitative insight, they become simplistic performance goals that can lead to counterproductive behavior. There is a wide consensus in the literature that the lion's share of value generated through university-industry knowledge exchange occurs via various forms of formal or informal collaboration. This is supported by data on universities' external funding, e.g. for British universities, where just 3 percent of the total income stems from licensing or sale of IP. By comparison, 30 percent is derived from contract research, 29 percent from collaborative research and 11 percent from consultancy (HEFCE 2015). This underlines the importance of moving away from using simple proxies and absolute performance counts as indicators of the value created at the interface between universities and industry. At the very least, current governmental efforts to broaden the set of indicators used to assess knowledge exchange and to recognize the importance of other, less visible mechanisms for university-industry interaction (as seen e.g. in Styrelsen for Forskning og Innovation 2014, 2015a) should be continued.

Better policymaking requires more systematic, holistic evaluations

Several studies lament the lack of high-quality, systematic evaluations of policies and policy instruments aimed at increasing university-industry collaboration and/or the commercial exploitation of university research. Evaluations are often focused on single programs or parts hereof and on the narrow objectives of a specific program, rather than the original and often more broadly intended effects that motivated the establishment of the program in the first place. Better, more informed policymaking requires more systematic evaluations, based on a sound intervention logic and using a relevant mix of state-of-the-art methods.

In addition, studies argue that many evaluations are aimed at relatively short-term objectives, driven by current political agendas and focusing on input and output additionality, rather than on identifying longer-term learning and innovation effects. This may lead to an underestimation of

[2] Credit for the phrase "proxies becoming goals" comes from Langford et al. (2006).

these effects and, in turn, underinvestment in R&D instruments.

Is increased collaboration and commercialization harming academic science?

Concerns have been raised that the increasing focus on collaboration with industry and on the commercialization of academic research may have unintended effects on the long-term progress of science. More precisely, there are concerns that researchers who engage with the private sector will shift their attention away from disinterested, long-term fundamental research towards commercially-oriented pursuits and more applied research that is easier to patent and/or has greater short-term commercial potential. By and large, the mounting evidence described in the literature suggests that these concerns are unfounded. There are but few indications that researchers will shift their research agendas towards more applied work with faster or greater commercial relevance. In fact, studies suggest applied problem-solving can provide valuable inputs to fundamental research, and that most researchers are unlikely to abandon their autonomy and scientific goals in order to pursue collaboration with industry and short-term commercial goals.

Moreover, the survey of the literature indicates that industry collaboration and scientific performance are complementary rather than competing activities. That is, researchers who engage with the private sector are likely to also show strong scientific performance in terms of high productivity (as indicated by the number of scientific publications they produce) and scientific impact (as indicated by citations to their publications). However, a handful of studies also find evidence of diminishing and possibly even negative returns to scientific performance, suggesting that it is possible for researchers to work *too* closely with industry.

Moreover, these findings tell us nothing about the direction of causality: are collaborating researchers better scientific performers *because* they engage with industry, or are they better at engaging with industry *because* they are excellent researchers? It is possible that neither is a consequence of the other, and that they are instead both related to other, unobserved factors such as for instance the personal characteristics of the researchers, the availability of additional resources, or the particular types of research problems that the researchers work on. As such, it cannot be extrapolated from these studies that *all* researchers who collaborate with industry will show strong scientific performance.

Also, more research is needed into the relationship between industry collaboration and *teaching*. Cooperation on teaching is one of the most used mechanisms for collaboration, yet we know almost nothing about how such collaboration affects the relevance or quality of teaching. A Danish survey revealed that 72 percent of university researchers experienced that collaboration with non-academic actors has a positive impact on the quality or relevance of their teaching (DEA 2014). Studies from the UK and China indicate that collaboration with industry has a neutral or positive impact on teaching activities.

Other concerns regarding university-industry collaboration are that the openness of science will be negatively affected by a decreasing willingness among researchers to share data and/or delays in publication of research results, and/or that patenting of academic research outputs may limit their diffusion and use (e.g. by other researchers) as inputs in further research and development activities. Here, the survey of the literature is less conclusive. Overall, delays and restrictions on access to public research do not appear to be a widespread or large-scale problem. However, there *do* appear to be instances where delays or restrictions occur. More study is needed to determine when and why they occur, as well as their severity and wider consequences.

Strengthening individual researchers' incentives and capacity to collaborate

The survey of the literature indicates that the key to boosting university-industry collaboration among public researchers is motivating more researchers to voluntarily engage with industry – and to help them do so in a productive fashion. The literature on researchers' motivations to engage in collaboration or commercialization activities emphasizes that these activities are essentially a question of personal choice and priorities. A number of individual and institutional factors can increase the likelihood that a researcher will engage with industry, e.g. being in an applied field or discipline, being affiliated with an institution with top-level commitment and institutional support for commercially-oriented activities, being older or in a more senior position, working in a university with a high share of external funding, or being affiliated with a university with high quality scientific research. In the end, however, it comes down to an individual decision, which is made largely based on the perceived costs and benefits of collaborating with industry, patenting or starting a spinout.

The literature provides convincing evidence that personal attitudes – i.e. towards industry collaboration and commercialization – are vital in shaping these decisions. For example, the review shows that even the *perceived* level of difficulty associated with patenting appears to be sufficient to discourage scientists from patenting, even when they are positive towards it.

The body of existing work suggests that more attention ought to be paid to perceived obstacles and incentives for the individual researcher. Also, the evidence indicates that researchers have different perceptions of industry engagement and entrepreneurial activities based on e.g. their scientific performance, academic position, age and motivations to engage with industry, suggesting the need to carefully consider how new policy initiatives are likely to impact different subsets of researchers in different ways.

The mounting evidence also makes it clear that researchers who choose to engage with the private sector do so not for financial gain but to reap benefits for their research and teaching. In fact, engaging with industry can provide important inputs to the traditional missions of research and teaching, e.g. additional research funding, access to materials or equipment, strengthened personal networks, or new ideas for promising academic research paths.

According to academic researchers in Denmark (with experience in engaging with industry), key barriers to increased collaboration with industry are lack of prioritization/reward from university management, and conflicting timeframes and goals in academia and industry, indicating that these barriers, whether real or perceived, should be addressed.

What are the main barriers to effective university-industry collaboration today?

R&D collaborations often fail or fall short of expectations. Termination of a project is not necessarily a bad outcome; however, termination of a project due to poor management or ineffective collaboration is.

Bruneel et al. (2010) identified two main barriers to collaboration, the first being "orientation-related barriers," which stem from differences in norms and behaviors among industry and academic researchers. These barriers can be reduced by collaboration experience, and are likely to be reduced over time as university-industry collaboration increases in volume and scope. Moreover, the growth in the number of PhD graduates in recent years has sent many young researchers into industry, which may work to further improve mutual insights.

The second main set of barriers are referred to as "transaction-related barriers," which include conflicts over ownership of intellectual property and conflicts over administration and bureaucracy. According to some studies, universities' growing focus on patenting and especially the potential financial gains from patenting, has contributed to conflict and may even have discouraged companies from entering into collaborations. The survey suggests that negotiations regarding the financial value of university-owned patents in particular can be a source of conflict.

Increased levels of trust between parties reduces both types of barriers, which underlines the importance of facilitating face-to-face contacts between industry and academia, and of supporting the development of overlapping personal and professional relationships.

Another possible barrier to effective collaboration identified in the literature is poor project management, not just by universities (as is commonly assumed), but also by firms. In fact, many firms have an ad hoc approach to their collaboration with universities, which is often driven by individuals rather than by a coherent, corporate strategy, implying that collaborations with academia are not designed or managed to the optimum effect. Moreover, the literature shows that firms are more likely to gain from their collaboration with universities when they show a persistent commitment to R&D and when they have sufficient absorptive capacity.

The review of the literature identified several factors that may, generally speaking, increase the chance of success in university-industry collaborations include: prior collaboration experience, employing multiple mechanisms for collaboration between the same parties, building/reinforcing trust among partners, higher R&D intensity (in industry partners), higher research quality (in university partners), geographical proximity and more professional management of the collaboration.

Excellent research is a necessary condition for strong commercial results

Generally speaking, the literature points to a strong relationship between high quality research and collaboration with industry. Institutions with excellent research receive more private funding and are more likely to engage in transfer of technology and knowledge to industry. Studies show that firms often prefer working with the best scientists – and that the firms who benefit the most from academic collaboration are the ones who work with high quality researchers. As mentioned earlier, academic researchers who are funded by, collaborate with and/or transfer research results to industry are also more likely to have a high scientific productivity and impact. Moreover, university scientists who are funded by their own university have a higher propensity to generate more original patents than scientists funded either by industry or other non-university organizations.

These findings indicate that high-quality, independent academic research is a prerequisite for effective university-industry collaboration and underline the importance of supporting excellent, long-term academic research.

What regional role can and should universities play?

Universities are often also expected to play a role in stimulating regional or local growth. Many countries, regions and cities have attempted to increase the returns from public investments in university research by encouraging or requiring universities to stimulate growth of local innovation systems, even though there is little evidence to suggest that universities are effective in creating such systems.

The results of the literature review indicate that policymakers set on strengthening universities' regional or local role should avoid generic "one size fits all"-approaches to stimulating regional or local innovation and growth; instead, policies should be tailored to the particular resources and challenges of the university and the local or regional system in question. Policies that are very explicit about which specific shortcomings of the system they are trying to remedy are likely to be more and thus effective.

The results of the review also indicate that policymakers should take care to set goals that are actually within the control of university managers and not dependent on critical factors that are beyond the reach of the university, such as the availability of funding or fiscal policies influencing the business environment.

Is university-industry collaboration for all firms? Arguments for a selective approach

In addition, policy approaches to stimulating universities' contribution to local or regional growth should consider the "quality" of the population of local or regional firms. Academic research indicates that university collaborations with less suitable companies effectively end up as "dead ends" for knowledge diffusion. Forming ties to less qualified industry partners can be justified based on a desire to transfer scientific knowledge to a large population of firms (a common theme in innovation policy), but is likely to result in many dead ends that bind resources that could have been put to more productive use. This points to the need for a more selective approach to the formation of university-industry ties, focusing on firms that have both sufficient R&D intensity and absorptive capacity *and* the specialized R&D needs necessary to engage productively with academic researchers.

So should universities work exclusively with R&D-intensive firms who have prior experience in collaborating with academia? Of course not. The survey indicates that it is more productive and effective for research-intensive and highly ranked universities (and researchers) to focus on collaboration with firms who have sufficient levels of absorptive capacity to allow for mutually beneficial collaboration and to avoid the type of "dead end" collaborations that are an inefficient use of public and private resources.

However, the literature also indicates that less research-intensive, more applied universities (and researchers) may be better suited than highly ranked universities for collaboration focused on the more immediate problems and information needs of firms, including firms who have limited or no experience in collaboration with academia. These universities should be supported and recognized in their efforts to collaborate with firms that have less R&D intensity and/or R&D collaboration experience. However, the literature also indicates that the firms they engage with should have problems that require or can at least benefit significantly from scientific or technological research expertise.

Finally, it is important that policies regarding universities' collaboration with industry consider the comparative strengths of different agents in the research and innovation system who can engage in R&D collaboration with firms. In Denmark, for example, this calls for a clear and efficient division of labor – and sometimes collaboration – between universities, other educational and research institutions, research technology organizations (like the Danish GTS institutes), private service providers, consultancies etc.

It takes two to tango: the role of industry in increasing the use of academic research

The contribution of public science to private growth also depends on firms' willingness and ability to translate that science into valuable new products, services and processes. Firms in many sectors of the economy are increasingly dependent upon specialized knowledge, skills and technologies in order to innovate. Many firms have therefore opened their labs to external collaborators, including academic researchers, in their efforts to cope with an ever-more complex, science-based nature of technological problem-solving, the increasing speed of innovation and growing global competition. But public science is but one of many inputs to private innovation, and one that very few firms draw on: in Denmark, less than 10 percent of innovative firms collaborate directly with academia, and just 2-3 percent of them indicated public science as a significant source of innovation in their organization.

In addition, private investments in R&D in Denmark have stagnated since 2010. This points to the need to stimulate private investments, which will probably call for either greater financial slack within the firms or for public R&D grants that can directly or indirectly (i.e. via collaborators) supplement firms' in-house R&D funding.

The role of public grants for collaborative R&D – do they work?

Public grants to stimulate R&D collaboration, e.g. between universities and firms, are a popular policy instrument. The aim of this type of public funding is to stimulate some form of "additionality", that is, desirable behavior or outcomes that would not have occurred in the absence of that funding. If not, the public subsidy is said to crowd out private funding, i.e. acting effectively as a substitute rather than a catalyst for private investment in R&D.

"Input additionality" refers to additional investments in R&D that occur as the result of a public grant. Though the evidence on whether public grants lead to input additionality is mixed, the emerging consensus seems to be that there is no crowding-out effect, and that some input additionality does occur. However, it has been pointed out that input additionality does not necessarily lead to increased innovation or value for society; for instance, investing more money in R&D in a firm does not guarantee a corresponding increase in the number or economic value of innovations generated by that firm.

Several studies find evidence of "output additionality" from public R&D grants – that is, a higher proportion of outputs from R&D than would have been produced in the absence of public funding – but the validity of these studies has been questioned in the literature. Moreover, studies of "output additionality" often focus more on direct outputs such as patents, scientific publications, prototypes, PhD graduates, and sometimes indirect outcomes such as new products rather than the more long-term effects, which are very difficult to measure yet by all accounts more valuable to society.

The evidence is equally mixed when it comes to public grants' impact on "behavioral additionality", i.e. changes in processes and behavior within the firm, which may lead to input and/or output additionality in the long term as a result of a public grant.

In short, there is no conclusive evidence that public R&D subsidies crowd out private investment; yet studies also fail to find evidence of substantial additionality. Why aren't studies of public grants for collaborative R&D showing better results? Part of the explanation might lie in the heterogeneity of these public schemes and the lack of robust, systematic evaluations of different schemes. Also, there appears to be substantial variation in project performance; many projects simply aren't as well designed or managed as they could or should be, which means that public schemes show a high degree of variation in their results.

Academic work moreover indicates that different types of grants are likely to generate different types of additionalities: while "research" subsidies are likely to stimulate R&D spending by firms, "development" subsidies appear to substitute such spending. This suggests that public programs should be focused on research projects rather than development projects in order to stimulate more R&D.

"Proof of concept" funding – the missing link in translating science to innovation?

The review also covers studies that point to a "Valley of Death" for early-stage university commercialization projects, where lack of incentives, capital and/or industry insight mean that promising inventions are abandoned before they have been sufficiently validated and matured to be able to attract private investors.

As a result, so-called "proof of concept" funds and centers are emerging in increasing numbers in both the US and Europe. The review points to the need to assess the current situation for proof of concept funding in Denmark and discuss whether there is sufficient funding available in Denmark today to bring promising university inventions to a point where they become attractive to private investors.

Time for a more balanced policy approach to universities' contribution to society

Policymakers have overestimated and overemphasized the role of direct, short-term commercial results of public science as the key to enhancing growth in the private sector. University research is, by definition, fundamental and long-term in nature. These characteristics of academic research lie at the core of the justification for public funding of science. As a result, most university research is embryonic and holds little intrinsic value until it has been developed through further research and development.

Short-term commercial applications of university research are, therefore, more likely to be a byproduct than a primary output of academic efforts. It follows that focusing on short-term commercial outcomes of university research is misplaced and potentially even counterproductive, as it may shift attention away from the results that universities are primarily designed to deliver to society: long-term, more fundamental building blocks of progress and innovation that other agents in the knowledge economy lack the incentives to develop. Short-term outputs and outcomes of university research should not come at the expense of universities' more fundamental, long-term contribution to R&D and innovation in industry, where public research organizations have a comparative advantage and their "raison d'être". As such, it makes sense to stimulate and support short-term spillovers from academic research alongside universities' long-term contribution to the public stock of knowledge and the development of new technologies. At the very least, the importance of maintaining long-term value creation over short-term commercial results should be recognized.

The review also suggests the need to move beyond trying to emulate anecdotal success stories and the overemphasis on the direct, short-term outputs of university research. This calls for more focus on quality rather than quantity in university-industry knowledge exchange. Policy towards stimulating knowledge exchange has had a tendency toward "more is better" approaches along the lines of "more patents and licensing deals are good; fewer patents and deals are problematic," or "universities should engage in more contractual relationships with more firms." The review of the literature suggests that a more reflective approach might be more fruitful, e.g. recognizing that fewer patents can be a sign of a more selective approach to identifying which inventions to patent, thus increasing the chances of further commercial development of the inventions patented. Or that building strong ties to fewer, more suitable firms may be more productive than trying to engage with many, less suitable industry partners.

Finally, the review also points to the need for flexible rather than "one size fits all" policies. The research literature documents a large degree of heterogeneity in models for and outcomes of university-industry knowledge exchanges across countries, regions, universities, disciplines, faculties and even individual researchers. Policies that take into account historical path dependencies, existing traditions and norms, and local resource levels are likely to achieve better results than standard solutions.

PART I. CHANGING POLITICAL EXPECTATIONS OF UNIVERSITIES AND THEIR INTERACTION WITH INDUSTRY

1. DRIVERS OF INTENSIFIED UNIVERSITY-INDUSTRY INTERACTION

This chapter reviews some of the major drivers for the increased focus on how we can promote an effective interplay between universities and the private sector. We examine the current role of universities in the knowledge society, where they are not just expected to produce new knowledge and skilled graduates, but also to contribute more directly to innovation and economic growth through greater interaction with industry and through efforts of their own to commercialize new research-based technologies.

We review how policymakers have intensified their demands for collaboration between research institutions and private firms in the search for increased returns on public investments in research.

Finally, we discuss how companies have opened their research and development laboratories to external collaborators, including academic researchers, to cope with the increasing pace of technological innovation, growing complexity, and international competition.

UNIVERSITIES: FROM IVORY TOWER TO ENGINE OF GROWTH?

Universities receive substantial public funding in return for creating value for society. The type of value they are expected to create, and the means by which they create it, are however subject to change, as a result of changing expectations and demands from policymakers (Audretsch 2014).

For most of the twentieth century, universities were primarily expected to contribute to society by undertaking and disseminating scientific research and by training new graduates through research based education. These two activities are often described as the traditional "missions" of the university. The rationale for their combination lies in the Humboldtian principle that teaching and research should be united in order to spur the advancement of knowledge through original, unbiased investigation, guided by logic and empiricism and independent from ideological, economic, political or religious influences (see e.g. Anderson 2004).

In recent decades, universities are also expected to fulfill what some have called a "third mission" (e.g. Branscomb et al. 1999; Etzkowitz & Leydesdorff 1997, 2000; Etzkowitz et al. 2000), namely to stimulate greater awareness and exploitation of university research outside academia.

The so-called "third mission" covers a broad range of activities, from disseminating research to the general public to engaging in direct collaboration with firms. It also covers actively pursuing the commercial exploitation of research results through licensing of university-owned patents and the creation of spinouts dedicated to developing commercial products based on university research.

Increasing focus on industry involvement and industry relevance in university research has been accompanied by the introduction of new terms to describe the relationships between actors in the research and innovation system. Terms like "mode 2" knowledge production and "triple helix" collaboration draw attention to the close interplay between sectors in the development of knowledge and innovation.

"Mode 2" knowledge production (Gibbons et al. 1994) is driven by problem-oriented research, undertaken in transdisciplinary cooperation between knowledge institutions and private firms, usually on tasks defined within specific application contexts. "Mode 2" knowledge production is defined in contrast to "mode 1", where the production of knowledge occurs through monodisciplinary research undertaken within "ivory tower" knowledge institutions, with limited or no involvement of industry.

The "mode 2" literature has been criticized for, among other things, its overly stylized picture of "mode 1" knowledge production (see e.g. Calvert & Patel 2003; Hull 1998; Llerena & Meyer-Krahmer 2003). Nonetheless, the widespread use of the "mode 2"-concept in policy circles suggests that it resonates with policymakers, presumably because of its focus on problem-oriented, interdisciplinary collaboration within and across the public and private sectors.

On a related note, "triple helix" collaboration refers to a close, ongoing collaboration between universities, industry and government. It emphasizes the increasingly prominent role played by universities in the knowledge society. Closely associated with the "triple helix" is the term the "entrepreneurial university", which sets out a proactive role for the university in promoting the application and commercial exploitation of university research. (e.g. Etzkowitz & Leydesdorff 1997, 2000; Etzkowitz et al. 2000; Ranga & Etzkowitz 2013)

The introduction of the notion of the entrepreneurial university is important because it is associated with certain changes in the behavior of universities, which are necessary if they are to meet the new "third mission" expectations. Audretsch (2014, p. 313) explained:

> ***Since the second world war, the university has evolved from a mandate and role characterized as the Humboldt model, with a primary emphasis on freedom and independence of scholarly inquiry and ''knowledge for its own sake'' to being a source of knowledge that is requisite for economic growth and a strong economic performance. While this increased the importance and significance of the university in terms of its impact on the economy, it did not greatly alter the functions and activities of the university. However, just generating knowledge did not ensure that knowledge would spill over for commercialization driving innovative activity and economic growth. The emergence of the entrepreneurial university gave universities a dual mandate—to produce new knowledge but also to alter its activities and values in such a way as to facilitate the transfer of technology and knowledge spillovers.***

Changes in the conceptualization of the role of universities in the knowledge society are largely driven by changes in policymakers' expectations and demands of universities, which we examine in the next section.

WHERE DID THE POLITICAL PUSH FOR GREATER RELEVANCE OF PUBLIC RESEARCH COME FROM?

In view of the substantial public funding which is invested in public science, it is unsurprising that policymakers debate on how these investments can contribute most effectively to society.

Universities' single most important channel for disseminating of knowledge and creating value for society is through the training of highly skilled graduates (Salter et al. 2003; Balconi & Laboranti 2006; David & Metcalfe 2009). Universities also make a number of other important contributions such as adding to the stock of useful knowledge, creating networks for the assessment and rapid diffusion of new information, and developing scientific instrumentation and new analytical and design techniques (e.g. Brooks 1994; Cohen et al. 2002; David et al. 1994; Grossman et al. 2001; Klevorick et al. 1995; Mansfield 1991, 1998; Mansfield & Lee 1995; Morgan & Strickland 2001; Narin et al.

1997; Rosenberg & Nelson 1994; Salter & Martin 2001; Salter et al. 2003).

Most university research is generic and often embryonic in nature (Rosenberg & Nelson 1994; Jensen & Thursby 2001). It can therefore easily take decades before the set of potential applications and thus the full impact on society of research can be reliably assessed. It is thus unsurprising that much of the science used in industry is "old" rather than recent science (Rosenberg 1994a). Outputs of university research therefore rarely hold intrinsic economic value before they have been incorporated into further research and development activities in the private or public sector (David et al. 1994). As a result, estimating the returns on public funding for university research is very difficult.

Rosenberg & Nelson (1994) argued that even though most university research can be described as fundamental in the sense that it involves studying and understanding phenomena on an elementary level, this fundamental nature does not in any way preclude practical relevance. In fact, they further argued that the bulk of academic research is guided by technological problems and utility-oriented concerns.

Some academic research, however, lends itself more easily to patenting and application than other research. For example, some research efforts are motivated both by a quest to achieve a fundamental understanding and by considerations regarding how the resulting knowledge might be used. Stokes (1997) described such research as "Pasteur's quadrant", named after the French chemist and microbiologist Louis Pasteur. Stokes highlighted the importance of understanding scientists' motivations for engaging in research, and introduced a distinction between "Pasteur's quadrant"-research, research which is solely driven by a quest for fundamental understanding ("Bohr's quadrant", named after Niels Bohr), and that which is driven primarily by considerations of use ("Edison's quadrant", after Thomas Edison).

"Pasteur-type" research is relatively common in biotechnology, computer sciences and aeronautical engineering. Academics who undertake such research may have a higher propensity to engage with the users of their research (D'Este & Perkmann 2011). Firms may also have a particular interest in working with "Pasteur-type" scientists, as they are likely to be positively inclined towards working with industry. Moreover, Baba et al. (2009) found that working with "Pasteur-type" scientists[3] increases firms' R&D productivity, measured as the number of registered patents.

On a related note, Bozeman et al. (2013, p. 4) introduced a distinction between *knowledge-focused research collaborations* – "aimed chiefly at expanding the base of knowledge and enhancing academic researchers' reputation and careers" – and *property-focused research collaborations* "dedicated, at least in part, on producing economic value and wealth for the researchers." The authors however recognized that "these are not hard and fast categories" (ibid., p. 5).

Whatever the motivations behind it, science is but one of many sources of innovation in firms (Laursen & Salter 2004), and one that few firms draw directly on (Tether 2002; Tether & Swann 2003). For example, just 9 pct. of innovative firms in Denmark collaborate with universities, and a mere 5 pct. collaborate with other public research institutions. Even fewer identify public science as a source of innovation for their firm: 3 and 2 pct. of innovative firms in Denmark indicated institutions of higher education and other

[3] Baba et al. (2009) defined "Pasteur-type" scientists as those university scientists who have been involved in many patent applications in addition to authoring many high-quality scientific papers,

public research institutions, respectively, as sources for in-house innovation (Danmarks Statistik 2014, based on 2012 data).

Collaboration between universities and the private or public sector is, however, by no means a new phenomenon (e.g. Rosenberg & Nelson 1994; Lee 1996; Tether 2002; Geuna & Muscio 2009; Palerai et al. 2015). In fact, interaction between universities and their surrounding community has played an important role throughout the history of the university (Martin 2003). Nor is there anything new about universities having to serve economic ends; for example, the German universities of the nineteenth century – including the early models for the Humboldtian university – were widely imitated precisely because they were believed to be an important factor in the success of German industry (Anderson 2010).

In fact, Martin (2003, p. 26) has argued that the so-called "third mission" for universities should be seen not as a new development but rather a shift back to an earlier model for universities' relationship to industry and society:

> ***… what is involved may actually represent more of a shift back towards the social contract embodied in the nineteenth century in the institutes of technology and technical universities, and in the land-grant universities in the United States. If this is so, the fact that science and universities were able to survive and to adapt to the social contract then in place gives grounds for optimism that they can do so again in the twenty-first century.***

Some things are, however, new, such as for instance the increased focus on the short-term outputs from public research and on universities' own role in institutionalizing interaction with industry and in driving the increased commercial exploitation of their research (Geuna & Muscio 2009; Carree et al. 2014). As a result, there has been a slow but continuous reorganization of universities from small elite institutions to multi-task organizations providing mass education, large-scale research and knowledge transfer. This process began in the US, then spread to Europe, starting in the UK in the 1980s, then moving to Northern Europe and, more recently, Southern European countries (Geuna & Muscio 2009). However, as Geuna & Muscio (2009, p. 98) pointed out,

> ***Universities vary enormously in the extent to which they promote and succeed in commercializing academic research. The identification of clear-cut models of governance for university–industry interactions and knowledge transfer processes is not straightforward.***

But where did the push for more commercial results from public science come from? Political expectations of universities to show a greater and more direct effect on innovation and economic growth, which are today pervasive in countries all over the world, can be traced back to the science policy debate in the US during the 1970s.

During the middle of the twentieth century, there was a substantial increase in arm's-length funding for university research in the US. During the first part of the century, the rise of science-based industrial laboratories and so-called "Big Science" had brought attention to the industrial and societal value of basic research, which therefore enjoyed substantial support among policymakers (Kline 1995). This support was only bolstered further by the successful application of basic research in chemistry and physics to the war effort during World War, most famously in the development of the atomic bomb (Kline 1995).

These developments contributed to a linear understanding among policymakers of how innovation occurs: basic research was seen as feeding inputs into applied science, which in turn resulted in the development of new products and services (see e.g. Langrish 1972; Godin 2003). Put differently, science came to be seen as an assembly line through which funding for basic scientific research would eventually lead to innovation (Wise 1985).

This linear view of the relationship between science and innovation was used to establish the rationale for increased science funding and significant autonomy for public research (Kline 1995). This view was further reinforced by the (now widespread) effort to measure the productivity and outputs of science; these efforts were driven, at least initially, by the US National Science Foundation. According to Godin (2003), these measurement efforts are key to understanding why the linear model of innovation continues to persist in research and innovation policy, even though it has long since been established that it does not accurately capture the complexity of science or innovation processes (see e.g. Wise 1985; Caraça et al. 2009). For instance, it does not take into account the complex, uncertain and often rather disorderly nature of innovation processes (Kline and Rosenberg 1986) or the importance of advances and problem-solving at the technological frontier as a driver of new research agendas in basic science (see e.g. Rosenberg 1982, 1994a, 1994b; Brooks 1994; Klevorick et al. 1995).

Nonetheless, around the middle of the twentieth century, basic science enjoyed a period of considerable growth in funding, based on the expectation that this funding was an investment that would result in new technology and innovation. This was not an unrealistic premise: numerous studies find evidence that science is a key source of innovation and economic growth. For example, studies have shown that around 10 pct. of the new products and processes introduced by firms would either not have been developed or developed with considerable delay were it not for the contribution of recent academic research (Mansfield 1991, 1998; Beise & Stahl 1999). Other studies have tried to measure the return on investments in public science and generally land on a conservative estimate of the return on investments in public science at somewhere between 20 and 40 percent. For reviews of this literature, see Salter & Martin (2001) or Frontier Economics (2014). On a related note, a recent study shows that there is a long-run welfare-maximizing rate of basic research investments, which is much higher than the rates we observe in OECD countries today (Prettner & Werner 2016).

However, as described earlier in the chapter, the link from science to commercial product is usually indirect and may take decades to materialize, making it exceedingly difficult to measure. Nonetheless, during the 1960s and 1970s, policymakers became increasingly dissatisfied with the lack of direct, easily measurable payoffs from public investments in research (Pavitt 2001). This dissatisfaction was fueled further by the oil crises of the 1970s and the competitiveness crisis of the 1980s, where the US faced new, strong competition from especially Japanese and German firms (Wise 1985; Florida & Kenney 1990; Pavitt 1991, 2001; Coriat & Orsi 2002).

American policymakers looked to the success of Silicon Valley and Route 128 and formed a strong belief that universities held the key to strengthening national competitiveness (Branscomb & Brooks 1993; Grimaldi et al. 2011). They consequently called for increased and closer collaboration between public science and industry (Calvert & Patel 2003) and for universities to orient themselves more toward industry and market needs (Calvert & Martin 2001).

Geuna & Muscio (2009) proposed a number of explanations why universities have been given so much attention in the global race to stimulate innovation and economic growth. Some of these are explanations are: a general recognition of the role of university-derived knowledge in driving innovation and productivity, the emergence of science and technology driven industries like biotechnology, nanotechnology and ICT, a growing demand for university graduates believed to be necessary in the knowledge economy, and an increasing reliance on universities as key actors in local and regional development. The authors also pointed to several explanations related to pecuniary motives, including a reduced motivation to fund university research for military purposes after the end of the Cold War, a growing focus on new public management with its emphasis on increasingly efficient government intervention, and government budget constraints.

The calls for greater industry orientation in academia quickly spread from the US to other parts of the world and were further bolstered by decreasing public funding for universities combined with increasing costs of scientific research (Geuna 1999, 2001), causing both policymakers and university leaders to look for new, external sources of income.

Income was especially expected to emerge from efforts to patent university research outputs and sell or license intellectual property (IP) to established firms or academic spinouts; this process is often referred to as "technology transfer". These efforts were facilitated by legislation that granted universities ownership of intellectual property emerging from their research and thus giving them a financial incentive to pursue commercialization (Mowery et al. 2001). This included the 1980 Bayh-Dole Act in the US and similar legislation in other countries (Mowery & Sampat 2005; Geuna & Rossi 2011), including in Denmark, where the Act on Inventions at Public Research Institutions came into force in 2000 (Baldini 2006; Valentin & Jensen 2007).

Experience has however shown that patenting and commercialization of university research are far more complex tasks – and far less lucrative – than originally imagined. The lessons learned from the past few decades of efforts to commercialize university research via the sale or licensing of university-owned patents and the establishment of spinout firms is reviewed in chapters 6 and 7, respectively, of this report.

Policymakers have also sought to encourage collaboration between universities and firms by, for example, establishing public programs to stimulate R&D collaboration or by building science parks and cooperative R&D centers. In chapter 8, we review insight into formal and informal modes of university-industry collaboration.

THE ROLE OF THE UNIVERSITY IN STIMULATING REGIONAL GROWTH

Universities are often also expected to play a role in stimulating regional or local growth, contributing to a sense of "mission overload" (Benneworth et al. 2016) in many universities.

Many countries, regions and cities have attempted to increase the returns from public investments in university research by encouraging or requiring universities to stimulate growth of local innovation systems (e.g. Cooke et al. 1998; Benneworth & Dawley 2005; Youtie & Shapira 2008), even though there is little evidence to support that universities are effective in creating such systems (Veugelers 2014). Indeed, a recent article argues that neither does university exogenously foster regional wealth, nor are universities endogenously shaped by regional wealth. Rather, regional wealth and universities follow an interlinked and co-evolutionary path (Lehmann & Menter 2015).

Nonetheless, at one end of the scale, universities face demands to stimulate local economic growth through both academic spinouts and through interaction with established firms. At the other end of the scale, universities are increasingly expected to engage themselves actively in their local neighborhood, involving themselves in projects with local communities (Breznitz & Feldman 2012) and even in local and regional governance (Goldstein & Glaser 2012).

The view of universities and their role in society has evolved alongside policymakers' models of how innovation occurs. Key shifts in these models have, as described by e.g. Soete (2007), evolved from the linear model of the post WWII-period, where autonomous basic science was seen as the key to progress, to a shift from science to technology and from low-tech to high-tech industries in connection with the oil crises, recession and increasing global competition seen in the 1970s and 1980s, to a growing focus since the mid-1980s on remedying weaknesses in "innovation systems" where universities, firms, governments and other actors interact to produce innovation.

The concept of “innovations systems” (e.g. Freeman 1987, 1991; Adams 1990; Lundvall 1992; Nelson 1993; Mowery and Nelson 1999) emphasizes the interplay between different types of actors in driving innovation, growth and competitiveness (Veugelers 2014) in countries (Lundvall 1992; Nelson 1993; Edquist 1997; Edquist 2005), regions (Cooke et al. 2000, 2004; Cooke 2001; Doloreux 2002), within specific technological fields (Carlsson 1995; Carlsson & Stankiewicz 1995) or within sectors (Breschi & Malerba 1997; Malerba 2002, 2005). In this perspective, innovation is brought forth through a collective process involving firms, universities, other research institutions, government authorities, suppliers of capital for R&D etc. Key elements of successful systems include actors’ ability to learn (and adapt accordingly), the existence and quality of ties between actors in the system, and the quality of the institutions (e.g. ICT, research and knowledge institutions, regulation e.g. on IP, innovation culture etc.) that influence the system.

The innovation systems literature is related to the literature on geographical clusters and other spatial agglomerations of economic and innovative activities, which, among other things, stresses the importance of spatial concentration of skilled labor, firms, and other key actors, shared costs of infrastructure development and maintenance, transaction efficiency, and of local knowledge spillovers for learning innovation (e.g. Audretsch & Feldman 1996; Baptista & Swann 1998; Feldman 2000; Malmberg & Maskell 2002; Beaudry & Breschi 2003; Bathelt et al. 2004).

All in all, the literature on innovation systems and geographical clusters highlight the role of universities as one among several key actors in a complex system. The important questions for policymakers in this perspective are how to ensure an optimal level and quality of interaction and learning among relevant actors. In fact, this literature has contributed to the development of the “system failure” rationale for public intervention in research and innovation activities. Whereas the traditional “market failure” argument centers on firms lack of incentives to invest in fundamental research and some forms of technological development (see e.g. Nelson 1959; Arrow 1962; Mowery 1998), the “system failure” argument focuses on shortcomings in the interaction between actors in the system or in the interactions that shape activities in the system (Smith 2000; Metcalfe 2005; Woolthuis et al. 2005; Chaminade & Edquist 2006). In contemporary innovation policy, either the two rationales coexist or the system failure argument tends to dominate (Steinmueller 2010; Bleda & del Río 2013).

So what *is* the role of the university in a regional or local setting? One of its functions at least is to make scientific insight available. For instance, Cowan & Zinovyeva (2013) analyzed the effects of the opening of new university schools in Italy during 1985-2000 and found that new schools increased regional innovation activity (as indicated by a change in the number of patents filed by regional firms) already within five years. The authors argue that this effect is brought about by the inflow of high quality scientific research to the region that occurs when a new university school is established.

Mowery & Ziedonis (2015) pointed to the importance of distinguishing between two broad categories of channels through which university research can impact regional economic or innovative activity: "knowledge spillovers”, that is, positive externalities from university research, and “market-mediated channels" such as technology licensing or various types of employment relationships between academic scientists and firms. They found that knowledge flows through market transactions (i.e. licensing) are more likely to be geographically localized than those operating through non-market spillovers. The authors argued that these findings reflect the incomplete nature of licensing contracts and the associated need for licensees to retain access to the academic inventors and their tacit knowhow. On a related note, Ponds et al. (2010) found, using data from the Netherlands, that while spillover mechanisms such as labor mobility or university spinouts are largely geographically localized, spillovers from research collaboration occurs over both shorter and longer distances, i.e. also at the national and international level. The authors argued that these spillovers from collaboration that occur over larger distances are generally neglected, which could lead to an overestimation of the importance of geographical proximity for academic knowledge spillovers.

Moreover, the effect of universities’ efforts to engage with local firms may vary from firm to firm. Giuliani & Arza (2009) studied university-industry ties in two wine cluster in Chile and Italy and found firms’ knowledge base and – to some extent – also the scientific quality of university partners to be a key driver of valuable linkages, understood as linkages that were more successful in promoting knowledge diffusion within regional clusters. They described linkages with firms with weak knowledge bases as “dead-ends” for knowledge diffusion, as such linkages do not appear to contribute to a further transfer of knowledge into the regional cluster. This implies that there are opportunity costs involved when academic researchers form ties to less suitable firms, which can be justified based on a desire to transfer scientific knowledge to a large population of firms, but which may as stated limit the effectiveness of the overall set of ties to industry that academics form. Based on their findings, the authors call for a more selective approach to the formation of university-industry ties. On a related note, Colombo et al. (2010) investigated the circumstances under which universities located in a geographical area contribute to the growth of local new technology-based firms. They found that universities influence the growth rates of local academic spinouts, but the effects on growth of firms are negligible. In addition, they found that the scientific quality of universities’ research has a positive effect on the growth rates of local academic spinouts, while the commercial orientation of research has a negative effect. The authors argued that their findings indicate that high-quality scientific research can enable universities to have a positive impact on the growth of local high-tech firms, but only if these firms have sufficient absorptive capacity.

David & Metcalfe (2009, p. 44) stressed the diversity in European universities’ their financing, governance, research/teaching balance and their interaction with industry – and warned against “one size fits all” approaches to stimulating economic growth in different regional innovation systems:

> ***Public policy-makers and university leaders must avoid confusing research and invention with innovation. Research discoveries and inventions certainly are needed to sustain innovation, yet universities are organisations with specialized capabilities and cannot exert effective influence upon many critical conditions -- financing, regulations, macroeconomic and fiscal policies affecting business investment demand – that govern the vitality of a region’s “innovation systems.” While stronger inter-connections between universities and businesses are to be encouraged, care must be taken in developing them to suit the particular circumstances of the participating organisations.***

Along a similar vein, Martin & Scott (2000) emphasized the importance of innovation policy taking into account sources of innovation failure in particular sectors, and tailoring policy responses accordingly. Tödtling & Trippl (2005) lamented the tendency among policymakers to – inspired by a handful of success stories from outstanding (particularly US-based) innovative regions – develop generic "best practice models" that are subsequently applied in a similar way across many types of regions. Similar points have been made by e.g. Cooper (2001), Benneworth (2004), Benneworth & Dawley (2005), Fini et al. (2011), and Veugelers (2014). As Benneworth & Dawley (2005, p 75) put it,

> ***… concern has been raised over the gulf between studies highlighting specific successful places, and generic arguments placing universities central to territorial knowledge-based development. Uncritical readings of these relationships have created "growth myopia" (Autio, 1997), focusing on a limited number of atypical high-science content, high economic-benefit and high-profile case studies, at the expense of understanding the mundane reality of the knowledge economy in 'ordinary places' (Benneworth, 2004).***

Benneworth et al. (2016) also warned against the idea of one-size-fits models for universities' impact on society in general and regions in particular, precisely because of the context-dependent nature of universities' engagement with their surrounding community. The authors called for universities to abandon "seeking simplistic best-practice third mission instruments elsewhere" (ibid., p. 1) and instead make efforts to better understand their own context and how they can improve their impact.

Typical elements of the standard models that Tödtling & Trippl (2005) criticized are a focus on high-tech, knowledge based and/or creative industries, emphasis on building up research excellence and attracting global companies, and aims to strengthen public-private links and stimulate the formation of spinout firms. Tödtling & Trippl (2005) cautioned against these "one size fits all" models for innovation policy in specific regions and argued that policy should be tailored to the particular preconditions and challenges of a given region. They introduced a distinction between central, peripheral and old industrial areas and identified three key possible challenges – a low level of clustering and a weak endowment of relevant institutions ("organizational thinness"), "fragmentation" i.e. a lack of networks and interaction between actors, and "lock-in" caused by historical path dependencies – in order to guide policy efforts in more tailored and effective directions. They argued (ibid., p. 1204) that

> ***Policy conclusions which are drawn from the analysis of "success stories" are only of limited use for less favoured regions, as their innovation capabilities deviate in many respects from these role models. This does not mean that no policy lessons can be learnt from leading dynamic regions. Nevertheless, a call for more differentiated innovation policies, dealing with specific innovation barriers in different types of regions, seems to be necessary.***

In the systems failure perspective, public intervention may be warranted if private organizations are unwilling or unable to innovate, i.e. a *problem* exists, and public organizations in the system have the *ability* to solve the problem (Edquist 2011). Shortcomings that call for intervention could include when the infrastructure for innovation is poor or lacking, when parts or all of the system are "locked-in" and thus unable to adapt to technological discontinuities), when linkages (e.g. among firms and universities) are missing or ineffective, or when there is insufficient learning among actors in the system.

In summary, the survey of the literature thus suggests that policies aimed at strengthening universities' regional or local role should acknowledge the specific role and comparative advantage of the university vis-à-vis other actors in the system, avoid standard policies but tailor the approach to the particular resources and challenges of that system, and be very explicit about the particular shortcomings of the system that the policy is trying to remedy.

Finally, Benneworth & Dawley (2005, p. 90) argued that

> ***It is important not to overemphasise the extent or significance of what emerges from universities innovation processes, not least because regional development activities remain a fairly small part of what universities do. Teaching and research are universities' core 'businesses' and the employment and spending multipliers that these generate may be much greater than the regional benefits of commercialisation activities.***

A GROWING OPENNESS IN FIRMS' R&D AND INNOVATION ACTIVITIES

Private firms have been investing in research and development since the Industrial Revolution (Bakker 2013), even in basic research (Rosenberg 1990).

Alongside changes to universities' approach towards collaboration and commercialization, private firms have however also seen significant changes to their research and innovation activities. In particular, many firms have intensified their efforts to access external sources of knowledge to enhance their in-house innovation and R&D activities (Belluci & Pennacchio 2015).

This development can be explained by several important trends, including pressure from rapid technological change, shorter product life cycles and increased global competition (Bettis & Hitt 1995; Chesbrough 2003; Wright et al. 2008). Moreover, many sectors are increasingly based on science and technology, which entails more complex R&D processes and increased use of non-internal technology development; that is, more technology is developed through outsourcing and R&D collaboration rather than in-house (Narula 2004). Meanwhile, relevant sources of knowledge are often distributed across several firms and research organizations, often located in different parts of the world (Chesbrough 2003). A firm's ability to tap into external sources of knowledge that is different from yet complementary to its in-house knowledge base can bolster the innovation activities and thus performance of the company, particularly in sectors where continuous acquisition of new knowledge and reconfiguration of competences is key to competitive performance (Belluci & Pennachio 2015).

In addition, the literature suggests that there is a significant pay-off from R&D collaboration. Several studies have shown that firms that engage in successful R&D collaboration have both stronger innovation performance (Belderbos et al. 2003; Becker & Dietz 2004; Sampson 2007) and better financial performance (Gemünden et al. 1992; Love & Roper 2004; Laursen & Salter 2006; Frenz & Ietto-Gillies 2009).

Public research organizations are some of the many specialist knowledge providers that firms engage with; other key knowledge providers include private research organizations and consultants (Tether & Tajar 2008). Collaboration with public research institutions specifically has been linked to stronger innovation performance, particularly in radical product innovation (Cassiman 2000; Monjon & Waelbroeck 2003; Drejer & Jørgensen 2005; Freel & Harrison 2006; Huang & Yu 2011; Köhler et al. 2012; Robin & Schubert 2013; Dornbusch & Neuhäusler 2015; Higón 2016), increased turnover from new products (Belderbos et al. 2004b; Lööf & Broström 2008), and improved productivity (Mark et al. 2015). Moreover, research has showed that firms that engage in basic science are more likely to produce breakthrough inventions (Malva et al. 2015).

However, achieving such results requires that collaboration is successful, which it often is not; we return to this point in chapter 5. The dynamics of collaboration can matter, too. Belderbos et al. (2015) found that, generally speaking, firms must engage in *persistent* collaboration with external partners (e.g. suppliers, customers, competitors and public research organizations) in order to obtain systematic, significant effects on innovative performance. The authors argued that these findings may be explained by the importance of the learning and build-up of trust that occurs during sustained collaborations, allowing the parties to engage in more effective collaborations. However, they also found evidence of a significant impact of recently formed collaborations with universities and other public research organizations on firms' innovative performance, suggesting that cooperation with science may generate substantial benefits to firms' innovation activities whether that cooperation has a transient or persistent nature.

LARGE BUT STAGNATING R&D INVESTMENTS BY DANISH FIRMS

Firms thus have a strong incentive to cooperate with, among others, public research organizations. In that respect it is relevant to note that Danish firms' investments in R&D correspond to 2 pct. of Danish GDP, compared to an EU-27 average of 1.3 pct.; however, these business expenditures on R&D in Denmark are driven in large part by the pharmaceutical industry (Danmarks Statistik 2014).

Danish firms appear to be stepping up both their domestic and their international acquisition of knowledge (Styrelsen for Forskning og Innovation 2015c).

However, a recent publication from the Danish Agency for Science, Technology and Innovation (DASTI) reported a stagnation in Danish firms' investments in R&D since 2010 (Styrelsen for Forskning og Innovation 2015b).; this is in marked contrast to the time of the most recent global financial crisis from 2007 to 2010, during which there was an overall increase in business expenditures on R&D. In comparison, expenditures on R&D in the private sector have been increasing in Germany and Austria and approaching the Danish, while investments in Finland and Sweden have fallen to almost the Danish level (Styrelsen for Forskning og Innovation 2015b).

The two main barriers to increasing R&D investments identified in a survey of Danish firms are lack of funding (61 pct. of firms) and lack of qualified labor and specialized competences (22 pct.). About half of the firms who identified "lack of funding" as a key barrier were referring to a lack of internal funding; one out of four firms who indicated "lack of funding" as a key barrier indicated a lack of public R&D grants. (Styrelsen for Forskning og Innovation 2015b). We return to the subject of public grants for collaborative R&D in chapter 4 of this report.

In the subsequent chapters, we examine both academic and industry motivations to collaborate with each other, and the key mechanisms by which such collaboration can take place.

2. MECHANISMS FOR UNIVERSITY-INDUSTRY INTERACTION

TECH TRANSFER AND SPINOUTS ARE THE "TIP OF THE ICEBERG"

Policy attention has been focused quite narrowly on patent sale or licensing and academic spinouts as vehicles for increasing the direct payoff on public investments in university research. However, as some academic researchers have pointed out, these mechanisms account for just the "tip of the iceberg" when looking at universities' overall interaction with industry and society at large (e.g. Salter 2002; Perkmann & Salter 2012).

Several studies underline the accuracy of this metaphor. For example, in a study based on data from the Departments of Mechanical and Electrical Engineering at Massachusetts Institute of Technology (MIT), Agrawal & Henderson (2002) concluded that patents are not representative of the overall generation or transfer of knowledge from a university. They based their conclusion on two key findings, namely that there was no relationship between patent volume and publication volume, and that firms who cited scientific papers from MIT generally differed from those that cited patents. In addition, faculty members in their study estimated that patents accounted for less than 10 percent of the knowledge transferred from their labs.

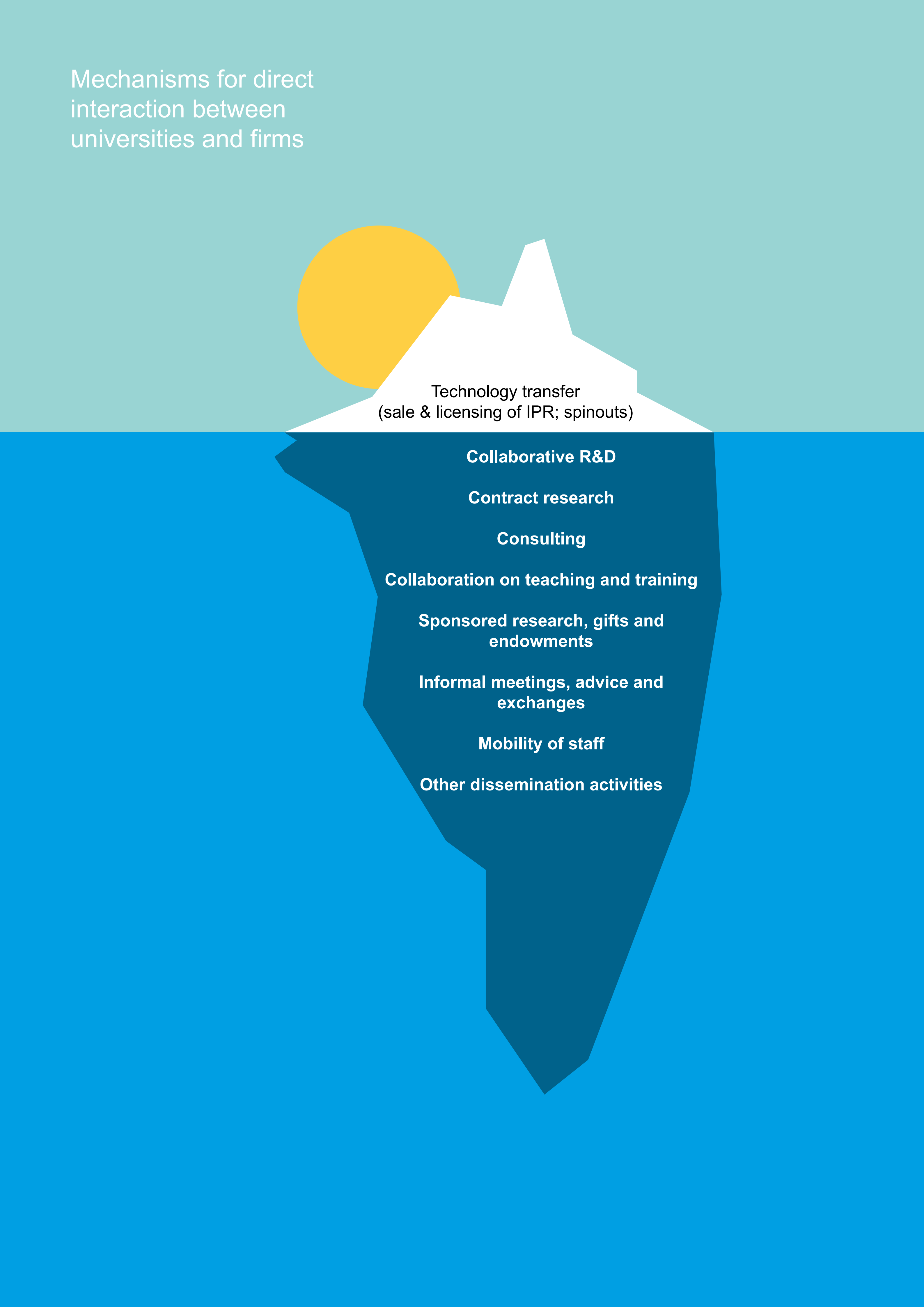
Studies based on European data confirm that engagement in various forms of direct collaboration with industry is far more common among academic researchers than involvement in patenting activities or the establishment of spinouts (Meyer-Krahmer & Schmoch 1998; D'Este and Patel 2007; Perkmann & Walsh 2007; Arvinitis et al. 2008). As D'Este & Patel (2007, p. 1297) pointed out,

> ***… too much attention on patenting and spin-off activities may obscure the presence of other types of university–industry interactions that have a much less visible economic pay-off, but can be equally as (or even more) important both in terms of their frequency and economic impact.***

Because of the inherent complexity of university-industry collaboration, case studies can be a valuable and indeed sometimes necessary tool to understand the antecedents, mechanisms and outcomes of such collaboration (Tijssen & Wong 2016). Using detailed case histories of the commercialization of academic patents, Feller & Feldman (2010) stress the complexity of the commercialization process, which goes far beyond a linear translation of a patent into a product. In the authors' own words (p. 614),

> ***Rather than the one-to-one, pipeline, correspondence between an academic patent and a technological innovation … the case histories highlight the highlight the dependence of the commercialization of a university-based patent on a complex, daisychain set of relationships involving faculty inventors, firms that may sponsor the academic research that leads to an [sic] university patent, firms that initially license the patent (at times to form a start-up firm) and those that bring the technology to market. … If any metaphor seems appropriate to describe the commercialization of academic research, it is that of a Rubik's cube.***

Moreover, based on a survey of researchers funded by a Canadian research council, Landry et al. (2007) found that researchers transferred knowledge much more actively when no commercialization was involved than when there was commercialization of protected intellectual property.


Mechanisms for direct interaction between universities and firms
Technology transfer
(sale & licensing of IPR; spinouts)
Collaborative R&D
Contract research
Consulting
Collaboration on teaching and training
Sponsored research, gifts and endowments
Informal meetings, advice and exchanges
Mobility of staff
Other dissemination activities

Olmos-Peñuela et al. (2016, p. 1) lamented the tendency in science policy to reduce societal benefits from investments in science and technology investments "to activities involving codifying and selling knowledge, thereby idealising best practice academic behaviours around entrepreneurial superstars." The authors called for greater attention to the broader set of mechanisms for achieving impact, including incorporating user knowledge into academic research processes - which they refer to as 'open research behaviors' - to increase the ease and/or likelihood with which research can be subsequently exploited outside academia.

A recent publication by Perkmann et al. (2015) describes an effort to offer a more comprehensive account of scientists' academic engagement and commercialization activities than hitherto available, by combining university administrative records from Imperial College London with data retrieved from external sources and surveys. The authors aimed to quantify 'independent' activity i.e. academic consulting, patenting and academic entrepreneurship that takes place outside formal university channels and usually goes undocumented. The study confirmed that conventional measurement approaches systematically underestimate the extent of researchers' engagement and commercialization activities and that a larger proportion of researchers than previously identified engage with the external community, when both independent and university-supported forms of interaction are taken into account. Moreover, independent channels for knowledge exchange are often key in transferring tacit knowledge from university researchers to industry. This is particularly important as only a small fraction of the research conducted in universities is codifiable in patents (Geuna & Muscio 2009).

Lawson (2013) pointed to the importance of collaboration with industry for turning commercial opportunities into patents, as the study showed that researchers who receive a large share of research grants from industry have a higher propensity to file a patent. This suggests interaction with industry can play an important role in shaping research paths and activities so as to increase the likelihood that promising research findings will find commercial applications.

In view of these findings, it is not surprising that licensing income from university-owned patents account for a very small part of the total income from British universities' knowledge exchanges with industry: just 3 pct. of the total income stems from licensing or sale of IP. By comparison, 30 pct. is derived from contract research, 29 pct. from collaborative research, 11 pct. from consultancy, and 17 pct. from continuing professional development and education. The remaining 9 pct. of British universities' income stem from regeneration and development programs and from facilities and equipment-related services. (HEFCE 2015)

Moreover, it has been argued that non-IPR based channels such as collaborative research, student and faculty mobility as well as contract research and consulting appear to be increasing in importance (OECD 2013).

All of this points to the need to focus more on transfers between universities and industry that focus primarily on interactions between university scientists and industry personnel, and where property rights are of secondary importance, though IP and non-IP based technology transfer can be difficult to distinguish from often in practice and indeed often go hand in hand (Grimpe & Fier 2010).

D'Este & Perkmann (2011) suggested that part of the explanation for why IP-based technology transfer and academic spinouts receive so much attention in research and in policy relative to their actual importance is that they are more easily measurable than direct collaboration. They also pointed out that not only is collaboration more frequent than transfer of IP and academic entrepreneurship; it is also more highly valued by industry. For example, a survey among R&D executives in the US showed that consulting – along with scientific publications, conferences and informal information exchange – was seen as more important channels for accessing university research than patents and licensing (Cohen et al. 2002). Several other studies confirm that firms tend to place a higher value on various forms of collaboration such as joint R&D projects or consulting than on licensing of university patents (see e.g. Roessner 1993; Klevorick et al. 1995; Schartinger et al. 2002). These findings are not surprising in light of mounting evidence on the limited economic value of university-owned patents; we return to this issue in chapter 6.

Interestingly, a survey among Dutch researchers in academia and industry (Bekkers & Freitas 2008) found that public and private scientists have similar perceptions of the importance of different channels for knowledge transfer, although university researchers attributed higher importance to all knowledge transfer channels than industry respondents.

FROM "TECHNOLOGY TRANSFER" TO "KNOWLEDGE EXCHANGE"

In recognition of the importance of the various modes of interaction between academia and industry, scholars as well as policymakers and practitioners have begun talking less about "technology transfer" in the strict sense and rather use broader, more inclusive terms such as "knowledge *and* technology transfers" or "knowledge *exchange*".

Arvanitis et al. (2006, p. 1866) define "knowledge and technology transfer" between academia and the private sector broadly as

> ***… any activities aimed at transferring knowledge or technology that may help either the company or the academic institute – depending on the direction of transfer – to further pursue its activities.***

On a similar note, Perkmann et al. (2013, p. 424) introduced the term "academic engagement", defining it as

> ***... knowledge-related collaboration by academic researchers with non-academic organizations. These interactions include formal activities such as collaborative research, contract research, and consulting, as well as informal activities like providing ad hoc advice and networking with practitioners.***

Perkmann et al. (ibid.) distinguish clearly between academic engagement on the one hand and commercialization oriented activities on the other, that is, IP based technology transfer and academic entrepreneurship.

Meanwhile, the tem "knowledge exchange" underlines that collaboration between universities and firms generally involves a two-way exchange of knowledge and ideas, rather than a one-way flow from academia to industry (Meyer-Krahmer & Schmoch 1998; Fier & Pyka 2014). It also stresses the often tacit nature of the transfer, while "technology transfer" is primarily associated with the transfer of codified knowledge and research results (Landry et al. 2007).

On a related note, D'Este & Perkmann (2011, p. 330) highlight the importance of direct collaboration – "highly interactive, 'bench-level' relationships" between individual researchers and industry partners – for realizing benefits of collaboration for academic research in the form of e.g. learning, access to industry knowledge, access to in-kind resources etc.

In view hereof, it is unsurprising that university-industry collaboration is often based on long-lasting personal relationships (Todtling et al. 2009), and which are typically established either informally through professional or even personal networks or formally through e.g. consultancy work, contract research or joint R&D projects (Cohen et al. 2002; D'Este & Patel 2007; Bishop et al. 2011).

Bishop et al. (2011, p. 31) described these personal ties "as valuable sources of knowledge that feeds into firms' innovation processes" and pointed out that they can open the door for researchers to provide industry contacts with direct assistance in problem-solving.

Assistance from academic researchers can e.g. help industry find alternative solutions to problems, locate specialized facilities or competences, assess the feasibility of project ideas, gain better insight into new scientific and technological opportunities, and provide ideas for new products and processes (Gibbons & Johnson 1974; Bessant et al. 2005).

Geuna & Muscio (2009) pointed out that despite the variety of mechanisms for knowledge transfer and collaboration with industry, only research contracts, IP-based transfer and spinouts have been institutionalized. Little attention is paid to the management of other channels such as personnel exchanges, publishing, consulting and participation in conferences. The authors also question the basis for the heavy emphasis on patents, arguing (p. 104) that

> ***The last few years have generally seen an increased reliance on academic IPR and spinoffs to more efficiently/effectively transfer knowledge from universities, although there is little positive empirical support for these methods.***

Along a similar vein, Veugelers (2014, p. 2) warns against knowledge and technology transfer policy focused too narrowly on patents and spinouts:

> ***… policy makers looking for ways to improve the contribution of universities to innovation based growth, should take a long-term perspective for developing an industry-science eco-system, avoiding the temptation of quick "success stories". A particular dangerous policy practice is a target focusing only on the commercialization of university technologies through academic patenting and spin-offs, ignoring the broader contribution to economic development with other pathways, most notably the research based training and mobility of human capital from universities.***

However, OECD (2012) argued that while policy approaches to promoting knowledge transfer in OECD countries has been centered on either "pushing" research out to industry through patenting, licensing and spinouts, or "pulling" industry needs in via contract research and collaborative R&D, these two approaches are increasingly integrated, suggesting a move towards a less linear approach to knowledge transfer.

KEY MECHANISMS FOR UNIVERSITY-INDUSTRY COLLABORATION

In the following, we present an overview of other key channels for interaction between academia and the business sector.

As described in the previous section, "technology transfer" is used, at least in the traditional, strict sense, to refer to activities undertaken with a view commercialization of research findings. This usually includes **patenting** and other forms of intellectual property protection of university research results.

Often the literature also examines **invention disclosures** by faculty members as an indicator of a willingness to engage in patenting.

IP is then sold or, more commonly, licensed to established firms or to **academic spinouts** founded specifically with the aim of developing commercial applications of outputs from university research.[4]

Collaborative or joint research and development are formal collaborations with the aim of cooperating on specific research and/or development projects (Hall et al. 2001; D'Este & Perkmann 2011). OECD (2013, p. 20) describe collaborative research and research partnerships as "situations where scientists and private companies jointly commit resources and research efforts to projects; research carried out jointly and may be cofunded (in relation to contract research); great variations (individual or institutional level); these range from small-scale projects to strategic partnerships with multiple members and stakeholders (i.e. public-private partnerships…)".

Many of the collaborations in this category can be described as "pre-competitive" and often receive public co-funding (D'Este & Perkmann 2011). They may also cover purely industry-sponsored research (Roessner 1993).

Another important form of collaboration is **contract research**, or original research commissioned and paid for by one or more firms. OECD (2013, p. 20) define contract research as "commissioned by a private firm to pursue a solution to a problem of interest; distinct from most types of consulting; involves creating new knowledge per the specifications or goals of client". The research undertaken is often more applied, i.e. more closely tied to specific application contexts and aims, than other collaborative research (Van Looy et al. 2004; OECD 2013).

Many academics also provide **consulting** to industry. This includes research or advisory services commissioned and paid for by one of more firms (see e.g. Perkmann & Walsh 2008). According to OECD (2013, p. 20) consulting and advisory services are the "most widespread activities – yet least institutionalised – in which industry and academics engage". Together, contract research and consulting represent the largest share of knowledge transfer activities (Muscio 2008, 2009).

Several other forms of interaction have been addressed in the literature (see e.g. Schartinger et al. 2001, 2002; Cohen et al. 2002; D'Este & Patel 2007; Bekkers & Freitas 2008; D'Este & Perkmann 2011), although they have received far less attention than technology transfer, academic entrepreneurship, and formal collaboration mechanisms. These include:

- **Indirect communication** through publication of academic papers, reports etc.; this channel is, unsurprisingly, particularly important in science-based sectors and firms (McMillan et al. 2000; Cohen et al. 2002).
- **Creation of joint facilities or sharing of facilities** (for instance laboratories or equipment).
- **Joint funding and/or supervision** of PhDs and Master thesis students.
- **Participation in joint meetings, conferences, workshops etc.**, whether organized by academia, industry or jointly.
- **Mobility of students or staff,** which can be a very effective way to transfer knowledge from academia to firms (see e.g. Zucker et al. 2002a, 2002b; Bekkers & Freitas 2008). This includes temporary staff exchanges (e.g. in connection with a joint project), time-limited or permanent positions for Masters' or PhD graduates coming directly from universities, and flow of university staff (incl.

[4] On a side note, Grimaldi et al. (2011) argued that one of the least recognized roles of universities in contributing to entrepreneurship is by giving their students a "protected space" in which they can experiment and pursue new ideas.

both postdocs and faculty members) into industry.

- **Informal exchanges and networking.** In addition to more formalized/contractual exchanges, university-industry collaborative relationships can also involve informal interaction such as providing advice on an ad hoc basis and casual networking activities (see e.g. Meyer-Krahmer & Schmoch 1998; Cohen et al. 2002).

In addition, firms may choose to **sponsor research** at a university or to provide **gifts, funding for chaired professorships and other endowments**. However, these are not strictly speaking collaborative relationships, and little studied in the literature, and therefore not expanded upon in this review.

Finally, Ponomariov & Boardman (2012) argued that the choice of channels for knowledge exchange and commercialization can be characterized and influenced by several dimensions:

- **The extent of direct personal involvement;** this is usually associated with the need to transfer tacit knowledge, which requires closer, personal interaction than the transfer of codified knowledge.
- **Significance to industry;** industry tends to value e.g. access to scientific publications and collaborative research higher than patent and licensing based channels (cf. Cohen et al. 2002; Agrawal & Henderson 2002).
- **Degree of knowledge finalization,** referring to the degree to which a research project provides a specific goal or can be contained in deliverables (e.g. contract research), as opposed to generating fundamental insight the applications and outcomes of which are difficult to anticipate or measure (e.g. publications, conferences)
- **Degree of formalization,** referring to the extent to which the interaction is institutionalized and/or guided by formal rules and procedures.

COLLABORATION AND COMMERCIALIZATION ACTIVITY AMONG RESEARCHERS IN DENMARK

DEA (2014a) undertook a survey of Danish university researchers' use and perception of a wide variety of mechanisms for engaging with non-academic actors in both the private and public sectors. The survey, which was partially funded by the Danish Agency for Science, Technology and Innovation, was sent to all full-time research staff (including Ph.D. students) at seven of the eight Danish universities.[5] 3,272 researchers completed the survey, yielding a response rate of 26 pct.

Survey responses revealed that three-quarters of respondents have engaged with the non-academic sector within the past three years. There was, however, substantial variation between disciplines and between universities, with the proportion of respondents from each university who had engaged in non-academic collaboration ranging from 66 pct. to 86 pct.

In addition, non-academic collaboration was more common among senior researchers than junior researchers. This is unsurprising, given that senior researchers are likely to be more visible and attractive partners to industry because of their academic track record and to have larger networks outside academia.[6]

[5] One university, The University of Southern Denmark, declined to participate in the study.

[6] See chapter 3 for a more detailed discussion of how age, academic position and other individual factors affect researchers' propensity to engage with industry.

The 75 pct. of respondents who had engaged in non-academic collaboration within the past three years were asked to describe the nature of that collaboration, by indicating the frequency with which they had made use of various mechanisms for collaboration. The main results from this part of the survey is summarized in figure 2.

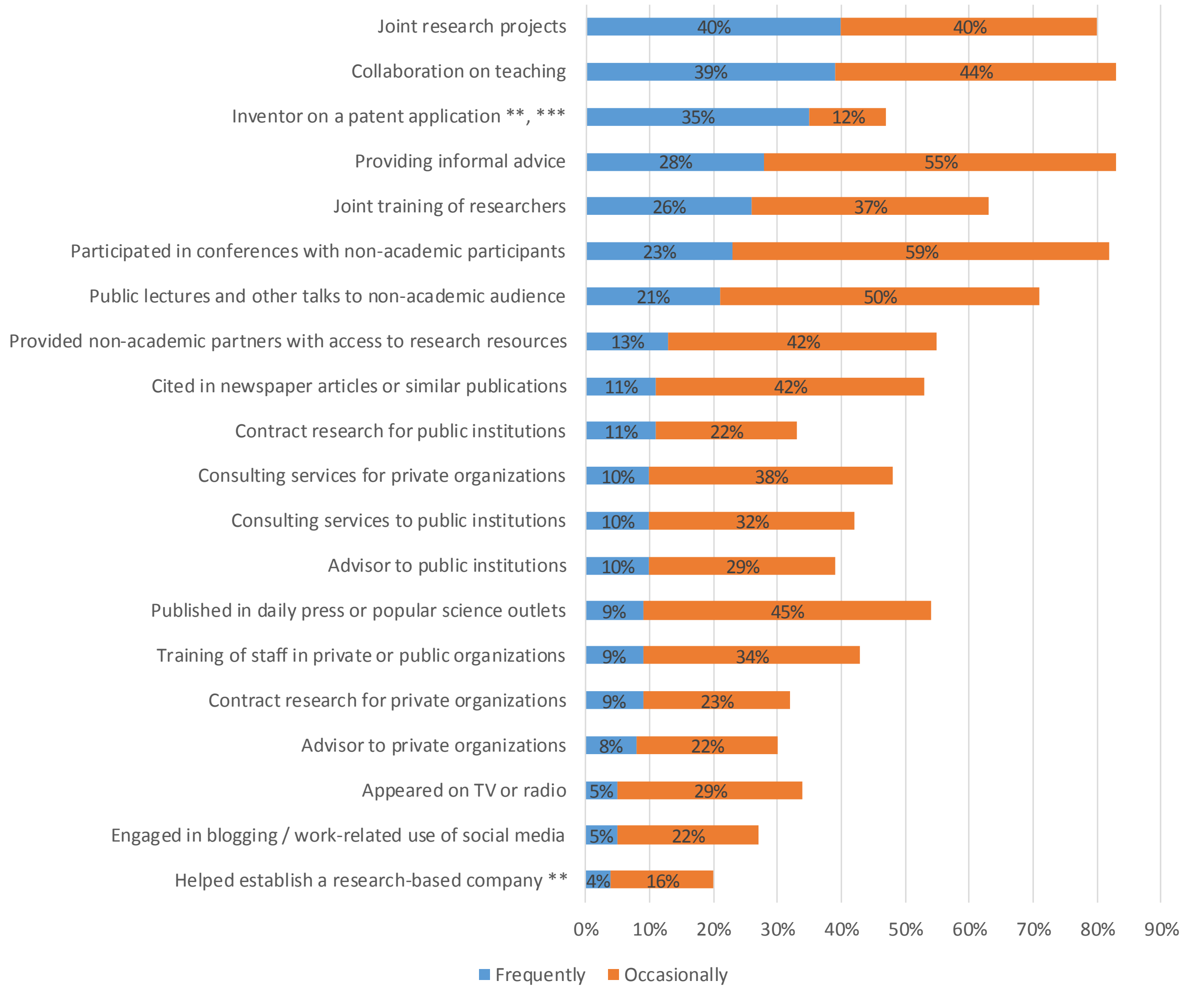
The survey data reveal that the collaboration mechanisms that researchers at Danish universities engaged most frequently in during the three year-period leading up to the survey in 2014 were joint research projects, collaboration on teaching of students and training of young researchers, and providing advice to non-academic actors on an informal basis. Overall, the results confirm international findings that researchers engage with the non-academic community through a broad range of additional formal and informal mechanisms and dissemination activities targeted at non-academic audiences.

Moreover, respondents from the wet sciences were asked about their patenting activity. 47 pct. had engaged in patenting within the past three years.

Finally, roughly 20 pct. of respondents helped started a company based on their own research at some point in their academic career. The percentage of respondents with entrepreneurial experience was similar for all universities and all scientific disciplines, including the social sciences and the humanities. There were, however, large differences in the types of companies started, as these range from one-man consultancies to research-intensive high-tech firms.

Interestingly, the survey revealed a very high degree of variation in individual researchers' collaboration behavior: no convincing patterns across universities, scientific disciplines, academic rank or scientific performance could be found in the types of non-academic collaboration mechanisms used by researchers, or in the degrees to which they use these mechanisms.

Figure 2. University researchers' participation in selected mechanisms for engaging in commercial activities and with non-academic actors over a three-year period * (2014 data)



Source: DEA (2014a). N.B.: Respondents who answered "never" hav<e been left out of the figure but are included in the number of observations. N(Patenting) = 1,539; N(Company) = 2,457; N(Joint research) = 2,386; N(Contract research for private organizations) = 2,267; N(Contract research for public institutions) = 2,260; N(Consulting to private organizations) = 2,293; N(Consulting to public institutions) = 2,291; N(Advisor to private organizations) = 2,267; N(Advisor to public institutions) = 2,289; N(Informal advice) = 2,424; N(Collaboration on teaching) = 2,407; N(Joint training of researchers) = 2,374; N(Training of non-academic staff) = 2,372; N(Conferences) = 2,415; N(Access to research etc.) = 2,384; N(public lectures) = 3,158; N(cited in publications) = 3,141; N(published articles) = 3,155; N(blogging, social media) = 3,140; N(appeared on TV or radio) = 3,140.

* The question re. establishing a research based company applied not just to the last three years, as the other questions, but to the respondents' entire academic career.

** Instead of the answer categories "frequently" and "occasionally", respondents were here asked to indicate if they had participated in patenting or the establishment of a spinout company "more than once" or "once", respectively.

*** The question re. patenting was not posed to researchers who had indicated that they work in the humanities or social sciences. Respondents were asked separately whether they had disclosed inventions to the TTO, but responses to this question were left out of the figure as they were almost identical to responses to the question regarding whether or not they had been listed as an inventor on one or more patents.

ARE THERE UNINTENDED CONSEQUENCES FOR SCIENCE?

A recurring topic in the discussion of universities' interaction with the commercial concerns whether this interaction will have a deleterious effect on either the participating researcher or the academic research community at large.

Academic research is built on different norms, incentives and reward systems than privately funded science (Dasgupta & David 1994). In some parts of the academic community, engaging with industry is seen as "selling out" (D'Este & Perkmann 2011). Studies also indicate that firms that collaborate with universities may indeed seek to influence the nature or dissemination of research, by attempting to direct university research (Newberg & Dunn 2002) or to gain proprietary control over the technologies resulting from a collaboration (Rappert et al., 1999).

Concerns have been raised that the increasing focus on collaboration with industry and on the commercialization of academic research may have unintended effects on the long-term progress of science (e.g. Nelson 1959, 2001, 2004; Feller 1990; Dasgupta & David 1994; Rosenberg & Nelson 1994; Slaughter & Leslie 1997; Metcalfe 1998; Cowan, 2005).

More precisely, three sets of concerns have been raised. First, that researchers who engage with the private sector will shift their attention away from disinterested, long-term fundamental research towards commercially-oriented pursuits and more applied research that is easier to patent and/or has greater short-term commercial potential (e.g. Blumenthal et al. 1996; Lee 1996; Florida & Cohen 1999; Jacobsson, 2002; Stephan et al. 2007; Fabrizio & Di Minin 2008; Azoulay et al. 2006). Second, that the openness of science will be negatively affected by a decreasing willingness among researchers to share data and/or delays in publication of research results (e.g. Dasgupta & David 1994; Nelson 1959, 2004; Czarnitzki et al. 2014). Third, that patenting of academic research outputs may limit their diffusion and use (by other researchers) as inputs in further research and development activities (e.g. Mowery et al. 2001; Nelson 2006), effectively leading to a privatization of the "scientific commons" (Heller & Eisenberg 1998; Murray 2005; Murray & Stern 2007).

Overall, the growing body of evidence points to the existence of a positive relationship between commercially-oriented activities and the quality of academic research. Some unanswered questions and possible grounds for concern remain, however. In the rest of the section, we review some of the key findings from the literature.

Industry collaboration and scientific achievement are complementary rather than competing activities. There is an emerging consensus that collaboration and commercialization activities are, by and large, positively related to indicators of traditional research performance for researchers who engage in such activities. Participating in commercially-oriented activities appears to be positively associated with strong academic performance.

This literature is reviewed and discussed at length by Larsen (2011) and Perkmann et al. (2013), and this review will therefore only highlight key findings.

A number of studies examine the relationship between scientific performance and various indicators of academic involvement with industry, including receiving industry funding (Blumenthal et al. 1996; Gulbrandsen & Smeby 2005), research collaboration and co-publication (Godin & Gingras 2000; Hicks & Hamilton 1999; Landry et al. 1996), contract research (Van Looy et al. 2004), academic patenting (Agrawal & Henderson 2002; Buenstorf 2006; Carayol 2007; Meyer 2006; Van Looy et al. 2006; Stephan et al. 2007; Baldini 2010; Grimm & Jaenicke 2015), and academic licensing and spinout creation (Buenstorf 2006; Lowe & Gonzalez-Brambila 2007).

Overall, these studies indicate that interaction with industry is positively related to high productivity – as indicated by the number of scientific publications researchers produce[7] – and, to some extent also appears to scientific impact – as indicated by citations to publications.[8] The survey of the literature indicates that engagement with industry and traditional academic pursuits are, generally speaking, complementary rather than competing activities.

This is further supported by Azoulay et al. (2007) who examined patenting behavior in a panel dataset covering almost 4,000 academic life scientists. While prior studies have shown researchers who patent to be, on average, more accomplished than their peers who do not patent, Azoulay and colleagues find that patenting events are preceded by a flurry of publications, suggesting that patenting behavior is also a function of scientific opportunities.

Does this mean that more collaboration or patenting is always better? Not necessarily. In fact, several academic studies have found evidence of diminishing returns of individual researchers' scientific productivity from collaboration with industry, or activities related to the patenting of research findings (e.g. Blumenthal et al. 1996; Bonaccorsi et al. 2006; Fabrizio & Di Minin 2008). More recently, Rentocchini et al. (2016) found, using data on Spain scienstists, that engaging in consulting activities is negatively correlated with scientific productivity for high levels of involvement in consulting activities. These findings suggest that there may be some optimum level of collaboration. In other words, working with industry may be highly compatible with strong research performance, but it appears that working too much or too closely with industry may be associated with diminishing or even negative impact on researchers' scientific productivity and impact.

It is important to stress that evidence of a positive relationship does not tell us anything about the direction of causality. Are collaborating researchers better researchers because of e.g. cognitive or financial inputs derived from their non-academic collaborations, or do firms collaborate with them because they are good researchers? In practice, both directions of causality probably play some role in explaining the positive relationship that we see between university-industry collaboration and scientific performance. Moreover, it is possible that neither is a consequence of the other, and that they are instead both related to other, unobserved factors such as for instance personal characteristics of the researchers, the availability of additional resources, or characteristics of the types of research problems that the researchers work on. (Larsen 2011)

The abovementioned studies examine the relationship between industry collaboration or involvement and scientific performance. But what about the relationship between industry engagement and the other key task of universities: teaching? This is little studied. However, in a study of the management of IP at 40 universities in the UK, Tang et al. (2009) found that while commercialization of research does not significantly affect the quality of teaching, it does not undermine the traditional research and teaching missions. More recently, Wang et al. (2015) use Chinese data to examine the relationships among universities' three "missions" and found

[7] While publication counts provide little if any information about the contributions made by academic researchers, they do represent a "reasonable measure of scientific production" (Martin 1996, p. 347).
[8] "Impact" is often used interchangeably with "quality". While related, these concepts are distinct. As Martin (1996) pointed out, "impact" refers to the influence that a publication has on surrounding research activities, by virtue of its contribution to knowledge but also other factors such as the affiliation and location of the authors and the language and status of the journal in which it appeared, whereas "quality" refers to a property of the publication, which is influenced primarily by the quality of the underlying research and the merits of the skill with which the article was actually written.

evidence of curvilinear relationships between teaching performance and both academic commercialization and academic engagement. Overall, the authors found that academic commercialization and engagement have a positive, combined effect on teaching activities.

Finally, a recent study finds no evidence that this relationship carries over from the individual level to the level of university departments. Based on data from the UK Research Assessment Exercise 2001, which is conducted at the department level, D'Este et al. (2013) explored whether university departments that engage actively with business also conduct research that is of high academic excellence. However, they found no systematic positive or negative relationship between scientific excellence and engagement with industry. In other words, the pursuit of academic excellence is neither supported nor hindered by engaging with the private sector. The authors argued that these findings suggest that the ability to reconcile excellence and engagement at the department level depends on the institutional context, the managerial capabilities and the strategic commitment of the department.

However, Czarnitzki et al. (2009) pointed out that there are different types of patents, which may involve different relationships with scientific publishing. Indeed, using data on a large sample of German university professors, they found that patents assigned to nonprofit organizations (incl. individual ownership of the professors themselves) complement publication quantity and quality, while patents assigned to corporations were negatively related to quantity and quality of publications.

Based on an extensive and detailed review of studies of university engagement, or collaboration, with industry, Perkmann et al. (2013) argued that evidence on the impact of such collaboration on research and teaching is too limited to assume that collaboration is always beneficial. The authors call (p. 432) for further research, for instance into the direction of the causal relationship between collaboration and scientific performance, to allow for effective policy interventions to be designed:

> ***If engagement spurs research performance, it is obvious that engagement should be promoted if policy-makers wished to promote better research. However, if the opposite is true – research performance drives engagement – interventions would need to promote research excellence leading to further engagement.***

Individual differences matter: some "star" scientists shine brighter than others. It is also relevant to ask if the relationship between academic performance and non-academic collaboration is equally strong for all researchers. Probably not. There are likely to be significant differences in researchers' ability to combine industry-oriented and scientific pursuits, as most performance measures in science are skewed. For example, a small number of researchers have a high number of publications, receive many citations and attract large amounts of external funding, while a large number of researchers have fewer publications and citations and secure smaller amounts of funding.

This may be partly explained by the "Matthew effect" in science and/or the existence of "star scientists". Robert K. Merton (1968) argued that psychosocial processes mean that scientists who are already successful and recognized are more likely to get credit for their contributions to science than lesser known scientists, even if their contributions are similar. He called this the

"Matthew effect"[9] to describe a mechanism by which "the rich get richer and the poor get poorer." This is in line with the idea of "accumulative advantage" in academic science (Cole & Cole 1973; Allison & Stewart 1974), namely the idea that the skewness in productivity among scientists can be at least partly explained by beneficial feedbacks on prior performance in the form of for instance recognition and resources.

Lynn Zucker and Michael Darby (see e.g. Darby & Zucker 2001; Zucker et al. 1998a, 1998b, 2002) introduced the notion of "star scientists", top scientists that seem to bring a "Midas touch" to everything they work on. For example, Zucker and Darby's work has shown that star scientists exhibit both superior scientific performance *and* entrepreneurial performance and therefore play a key role in both the development of science and in its successful commercialization, particularly within emerging fields of technology such as biotechnology and nanotechnology. These star scientists, while valuable assets to their departments, are not representative of the general population of academic researchers.

On a related note, Breschi et al. (2007) pointed to the possible existence of an "individual productivity effect", whereby both publications and patents may be seen as proxies for individual scientists' abilities. According to this line of thought, a highly accomplished scientist would be likely to exhibit both higher publishing and patenting activity than less accomplished peers. Similar phenomena have been described by Azoulay et al. (2006) as "within-scientist economies of scope" and by Stephan et al. (2007) as simply "the right stuff."

It is likely that the positive relationship found in many studies between academic performance and non-academic collaboration is driven as least partly by the presence in the data of some particularly successful, visible and/or well-networked researchers. As such, we cannot expect that all researchers who engage in non-academic collaboration will show strong research performances. This indicates that caution should be exercised in extrapolating findings from the studies mentioned above to the entire population of academic researchers.

Is there an impact on the nature or dissemination of academic research? Some studies find evidence that sponsorship from or collaboration with industry can hinder or delay the public disclosure of academic research (e.g. Czarnitzki et al. 2014). Larsen (2011) and Perkmann et al. (2013) provide more detailed discussions of the existing body of academic work on this topic.

A survey of Danish university researchers' collaboration with the public and private sector (DEA 2014a) asked respondents to assess the extent to which collaboration with industry affected the dissemination of academic research. 8 pct. of researchers who had engaged in collaboration with non-academic partners within the past three years indicated that such collaboration "always" leads to restrictions on the availability of research data and/or results to other researchers is restricted by non-academic partners; 33 pct. indicated that this is "sometimes or occasionally" the case, and 36 pct. had "never" experienced it.

Respondents were also quizzed about publication delays: 7 pct. "always" experienced delays as a result of collaboration, and 31 pct. "some-

[9] Merton (1968, p. 58) coined the term with reference to the Gospel According to St. Matthew, citing the passage "For unto every one that hath shall be given, and he shall have abundance: but from him that hath not shall be taken away even that which he hath".

times or occasionally" found their research subject to delays. 38 pct. of respondents never experienced publication delays as a result of collaboration with non-academic actors.

Assuming that respondents' assessment of these effects are reliable, this indicates that problems with restricted or delayed dissemination may be primarily experienced by a subset of researchers, firms or collaborations. Further investigation is needed to ascertain when and why these negative impacts are experienced.

Scientists that are involved in licensing may themselves choose to delay disclosure of their research results (Chang & Yang 2008). On a similar note, Walsh et al. (2007) showed that academic researchers engaging in commercial activities can lead to restricted access to research materials, data and unpublished information. Moreover, using data from a survey among German scientists, Czarnitzki et al. (2015) found that scientists who receive industry funding are twice as likely to deny requests for research inputs as those who do not. Interestingly, scientists who receive external funding of any kind, public or private, are 50 pct. more likely to be denied access to research materials by others. On a related note, Hong & Walsh (2009) found that secrecy in academia has indeed increased, and that this increase appears to result from a combination of increasing commercial linkages and increased pressures from scientific competition. They also found, among other things, that industry funding is associated with more secrecy, while industry collaboration is associated with less secrecy.

Overall, however, there is limited evidence from the academic literature that increasing involvement with industry has severely restricted the openness of science and availability of research outputs for use in further research or that academic research is becoming skewed towards more applied topics (Larsen 2011; Perkmann et al. 2013).

For instance, Murray & Stern (2007) found modest evidence that patenting may lead to slight decrease in the use and/or diffusion of scientific research.

Jensen & Thursby (2004) found no evidence that incentives to engage in patenting had negative consequences for fundamental research in universities. On a related note, Thursby et al. (2007) concluded that engaging in increased licensing activity has no negative impact on time spent undertaking basic research; rather, they proposed that time spent on licensing replaces researchers' leisure time.

Studies suggest that applied work may even benefit scientific research. For instance, Perkmann & Walsh (2009) investigated university-industry collaboration in engineering and found that applied (as opposed to basic) research projects can enable academics to engage in exploratory learning, which in turn can open up new research paths and projects, particularly for academics who engage in multiple relationships with industry.

On a related note, D'Este and Perkmann (2011, p. 332) found indications that academics' motivations for engaging with industry – a topic which we address in chapter 3 – may influence how that engagement affects their research:

> ***… the impact on academic research of industry engagement may differ according to the motivations driving interactions. When academics work with industry primarily to further their research, negative impacts on the direction of their research or on their research productivity will be arguably less likely. This holds particularly when academics are motivated by learning and access to resources. Our data suggest that this type of collaboration is less likely to result in immediately commercially relevant outputs, such as patents and spin-offs. At the same time, however, in the longer term, engagement in relationship-intensive collaboration with companies might***

enhance academic research output and generate university benefits via better research evaluations and higher levels of funding.

D'Este & Perkmann (2011) argued that academic researchers place great emphasis on retaining their autonomy and ensuring that their interaction with industry is at minimum compatible with and preferably conducive to their research activities. The authors therefore suggest that universities seeking to increase staff incentives to engage with industry should focus on promoting cross-fertilization that creates value for both academic research and industry applications, rather than encouraging university researchers to become entrepreneurs.

A number of studies indicate that engaging in commercially oriented activities may be linked to a shift towards research that is oriented or even targeted towards commercial use and exploitation, regardless of whether it might be described as "basic" or "applied" (see e.g. Azoulay et al. 2006; Fabrizio & Di Minin 2008).[10]

Finally, some recent work (Crespi et al. 2009) suggests that patenting activities may be crowding out other forms of university-industry collaboration, but the work is very preliminary suggesting the need for further research on this topic (Geuna & Muscio 2009).

All in all, the body of findings points to the need for further insight into the particular characteristics, benefits and disadvantages of different mechanisms for collaboration, and the relationship between academics' motivations to collaborate and the mechanisms by which they do so.

What is at stake? The growing involvement of academic researchers in commercially-oriented activities prompts questions about the overall mission of the university (McKelvey & Holmén 2009). The contemporary rationale for the division of scientific labor into public and private domains, which dates back to the late 1950s, presents a case for publicly funded research in basic science (see Arrow 1962; Nelson 1959). Because the results of basic research are difficult to appropriate, private individuals and firms lack incentive to engage in it. Basic research, with its open-ended and generic qualities, however, holds a potentially large payoff to society as a whole. It is therefore in the interests of society to fund such research in autonomous institutions, which are distinct from its key beneficiaries, and to ensure the free and wide dissemination of research results.

As such, Nelson (1959) argued that universities should, insofar as possible, be relieved of the "burden" of applied research that draws their resources away from fundamental scientific research, precisely because their comparative advantage lies in basic research and the dissemination of its outputs. Thus, increasing commercial orientation and industry involvement can be problematic if they serve to shift researchers from the social roles in which they are most efficient, as suppliers of a collective good – scientific and technological knowledge (Feller 1990).

Similarly, Dasgupta and David (1994) argued that academic and industrial/military science rest on distinct norm and incentive systems that should be kept separate; blurring the bounda-

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[10] It can be questioned whether it makes sense at all to seek to measure a shift from basic to applied research. Calvert (2004, 2006) pointed to the lack of consensus regarding the definition of basic research and argued that it "is a flexible and ambiguous concept" (Calvert, 2006, p. 199) with many dimensions that are selectively brought into play by scientists and policy makers in order to gain authority or access resources. Any theoretical boundary between basic and applied research is therefore, by definition, a blurred and artificial distinction (Larsen 2011). As an alternative, Stokes (1997) introduced the Pasteur's quadrant, which classified research according to two dimensions: whether or not the research is concerned with achieving a *fundamental* understanding of the phenomenon of study and whether or not it is concerned with the *use* of research results. More recently, McNie et al. (2016) have suggested an alternative, more nuanced set of terms with which to characterize science; for instance, the authors introduce a distinction between "science-centric" and "use-oriented" research as to opposite ends of a spectrum of research defined by its context of use.

ries between the two systems upsets the synergistic equilibrium between them and may therefore lead to a sub-optimal allocation of public resources.

On a similar note, Metcalfe (1998) proposed that the growth of scientific knowledge is premised upon an increasingly fine division of labor in which different sets of research institutions are adapted to specific purposes. He also argued that a key aim of science and technology policy is to create links between these different institutions, encouraging productive collaboration between them, with the ultimate objective of maximizing the long-term benefits from investments in scientific research, and that making universities behave more like firms could constitute a step in the wrong direction.

> ***It would be as foolhardy to make academic institutions commercial as it would be to make private firms non-commercial. The division of labour between them is not accidental and the central problem of policy is how to connect these different institutions together in a more productive fashion. (Metcalfe 1998, p. 108)***

PART II. MOTIVATIONS FOR AND BARRIERS TO COLLABORATION

3. WHEN AND WHY DO ACADEMICS ENGAGE WITH INDUSTRY?

Academic researchers are widely recognized to be motivated by a different set of values and goals than researchers in industry. Dasgupta & David (1994) argued that industrial scientists function within a community of "proprietary science" and are as such chiefly concerned with generating rents from the appropriation of the knowledge and inventions that they bring forth.

In contrast, academic scientists operate within a community of "open science" governed by the Mertonian norms of science, namely universalism, disinterestedness, originality, skepticism, and communalism, that is, the belief that knowledge and discoveries generated through publicly funded research should be placed in the public domain (Merton 1973). Scientists are rewarded with promotions and funding in exchange for generating and disseminating new knowledge; they are typically driven more by the desire to obtain the recognition of their academic peers than by the possibility to achieve personal financial gain (ibid.). Scientific publications are one of the primary means of disseminating research results to the scientific community, and establishing priority is essential to attaining publications and scientific prestige (Dasgupta & David 1994).

But what factors affect researchers' propensity to engage in collaboration with firms or in efforts to commercialize findings from their research? In this chapter we review literature on factors that influence academic researchers' likelihood to engage with the non-academic world, their motivations to do so, and the impact of such engagement. Please note that some of the studies reviewed in this chapter deal with motivations to interact with industry in general, while other deal only with one or more specific channels for interaction, e.g. collaborative research or patenting.

THE ROLE OF SCIENTIFIC FIELD AND ORGANIZATIONAL FACTORS

Scientific field or discipline. Studies of university-industry collaboration consistently reveal that some scientific fields or disciplines are more prone to collaborate with the private sector than others or to engage in patenting and spinout formation. Generally speaking, this is particularly true for the applied sciences in general or more specifically for life sciences, engineering, technical sciences and – according to some studies – the natural sciences and parts of social sciences e.g. economics and management studies (e.g. Lee 1996; Powell et al. 1996; Bozeman 2000; Schartinger et al. 2002; Azagra-Caro et al. 2006; Arvinitis et al. 2008).

Local policies, norms and institutional support. The literature shows that individual factors explain much of the variation in collaboration and commercialization behavior, with institutional factors playing a smaller part (D'Este & Patel 2007; D'Este & Perkmann 2011). Much of the focus has been on the role played by the TTO, which is both in charge of protecting the institution's intellectual property and helping academic staff commercialize their research (Jensen et al. 2003). TTOs have however been shown to play only a marginal, indirect role in actually driving academic researchers to enter into a new venture (Clarysse et al. 2011a).

Some studies however indicate that policies and support mechanisms at the university can promote industry orientation in academics. For example, Baldini et al. (2007) found from a survey of 208 Italian academic inventors that patent regulations at the university-level can reduce obstacles to patenting as perceived by researchers, by signaling organizational commitment to patenting activities. Huyghe & Knockaert (2014) found that universities which explicitly reward people for 'third mission' related show higher levels of spin-off and patenting or licensing intentions.

However, Fini et al. (2009) found that universities investments in mechanisms to support spinout-formation did not strengthen researchers' incentives to start a company; instead, such decisions were driven by the expectation of personal benefits, notably an improved academic position.

In addition, official policies may also lead to symbolic rather than actual changes to behavior: Bercovitz & Feldman (2008) argued that researchers' may engage in symbolic, or superficial, compliance with local policies regarding entrepreneurial behavior, pretending to live up to expectations or requirements instead of actually altering their behavior. Actual entrepreneurial behavior, the authors argue, requires certain conditions to be met, e.g. that local entrepreneurial norms exist within the faculty group.

Peer effects. Kenney & Goe (2004) found that working in an academic department or disciplines with cultures that are supportive of entrepreneurial activity can counteract disincentives created by a university environment that is not. Generally speaking, the behavior and values of peers in the scientific community is likely to influence academic researchers' decisions about whether and how to engage with industry (Perkmann et al. 2013). Based on data on researchers in the UK, Tartari et al. (2014) found evidence of peer effects in researchers' decisions engage with industry. In particular, they found that lower-ranked and younger researchers are influenced by the collaboration behavior of peers in their immediate social environment.
On a related note, using data on scientists at Swedish and German universities, Huyghe & Knockaert (2015) found that the extent to which universities articulate entrepreneurship as a key part of their mission stimulates scientists' intentions to engage in spinout creation; moreover, the presence of university role models was found to positively affect research scientists' propensity to engage in entrepreneurial activities.

Moog et al. (2015) examined the impact of skills, working time and peer effects on scientists' entrepreneurial intentions. They found, using data collected from life sciences researchers in Germany and Switzerland, that scientists are more likely to have higher entrepreneurial intentions if they have a more diverse and balanced skill set (i.e. are "Jacks-of-all-trades" rather than highly specialized), but only if they also balance their working time and are in contact with entrepreneurial peers. The authors therefore underscore the importance for promoting entrepreneurship of ensuring that scientists, among other things, have balanced working time allocations across different activities and that they work with entrepreneurial peers, i.e. scientists who have experience starting spinouts.

Thus, researchers who work in research environments where collaboration (or commercialization) is common are more likely to engage in collaboration (or commercialization) themselves, particularly if they are new to the academic community. This finding is not surprising in view of prior research indicating that organizations and the individuals within them learn by drawing on personal experience or inferences from information about experience gained by others (Levinthal & March 1993).

Size. The evidence on the importance of department or university size is mixed. For instance, in a study based on data from 309 Austrian university departments, Schartinger et al. (2001) identified department size as a significant determinant of university interaction with industry, both in terms of the overall volume of interaction and the likelihood of engaging in specific types of interaction. However, other studies (e.g. Arvanitis et al. 2008) have controlled for department size but found no significant, systematic effect on the likelihood of participating in knowledge transfer, collaboration or commercialization activities.

For example, Huyghe & Knockaert (2014) found that universities which explicitly reward people for 'third mission' related show higher levels of spin-off and patenting or licensing intentions.

Funding. Not surprisingly, several studies show that collaboration tends to be correlated with higher levels of external funding, particularly from private sources. Institutions that succeed in attracting external funding are likely to have a high quality of research and good networks to external funders and collaborators, which in turn increases the likelihood of attracting more funding. For example, Friedman and Silberman (2003) studied invention disclosures at 83 American universities and found that the number of invention disclosures was positively associated with, among other things, the volume of external funds awarded to universities (both from public, federal sources and from industry).

On a related note, based on a survey of university-industry interaction in 241 scientific institutes in Switzerland, Arvanitis et al. (2008) found a significant and positive relationship between a high share of external funding and higher propensity to partake in knowledge and technology transfer activities.

Research quality. A number of studies have examined the relationship between quality of research undertaken at a university and researchers' engagement with the private sector. The previously mentioned study by Friedman and Silberman (2003) found that the number of invention disclosures at American universities was positively related to the quality of universities' faculty.

In the aforementioned study on data from Austrian university departments, Schartinger et al. (2001) found that research characteristics such as the number of international scientific publications per researcher were significantly related to participation in joint research with industry. Volume of publications is not an indicator of research quality, but can at least serve as a proxy for some level of scientific activity that meets academic standards, provided that the publications were in peer reviewed journals.

In a study of 800 cooperative agreements between Spanish firms and research organizations, Mora-Valentin et al. (2004) found that even the *perceived* reputation of public research organizations was positively and significantly associated with the perceived success of cooperative projects. Moreover, Lee & Stuen (2015) argued that universities' reputation can also play a role in the success of their technology transfer activities. Using data on researchers from the nanosciences, the authors found evidence of a strong positive relationship between the university's reputation in nanosciences and the number of patents assigned to the university (rather than to firms). They also found that the share of license revenue offered upfront to researchers was positively associated with university-assigned patents, but negatively related to firm-assigned patents. All in all, their findings suggest that improving universities' research reputation through support for basic research may improve technology transfer performance.

On a related note, using a dataset covering all UK universities, Perkmann et al. (2011) found that the relationship between departmental faculty quality and industry involvement differed. For example, they found a positive relationship in the technology-oriented disciplines. They also showed faculty quality and industry involvement to be positively related in the medical and biological sciences, but not for star scientists. In the social sciences, they found some support for the existence of a *negative* relationship between faculty quality and particularly the more applied forms of industry involvement.

RESEARCHERS' BELIEFS AND PERCEPTIONS MATTER

A recent study of external engagement activities by 4,400 researchers in 31 higher education institutions in Norway (Thune et al. 2016, p. 1) concludes that

> ***… university-level variables explain few of the differences in external engagement among academic staff in general.***

In fact, a number of studies suggest that characteristics and perceptions of individual researchers are more important than organization-level characteristics in understanding university researchers' propensity to engage with the private sector. The explanation for this has to do with how work is organized. Universities can be described as professional bureaucracies (Mintzberg 1983) whose employees have considerable degrees of freedom in choosing which activities to partake in with a view to achieving the goals of the organization (D'Este & Perkmann 2011). Moreover, while activities such as undertaking research and teaching are mandatory for most university researchers, industry- and impact-oriented activities are typically optional (ibid.) and ultimately a question of personal choice (Lee 2000; Thursby & Thursby 2004; Azagra-Caro 2007). Lee (2000, p. 13) argued that

> ***After all, it is the individual faculty member, not the university, who conducts research. And given the faculty job responsibility – teaching and research – collaboration with industry is but tangential to the main mission and essentially a matter of personal choice. This suggests that were faculty members to collaborate with a firm and maintain the relationship, they must realize significant benefits, the benefits that would excite them.***

University patenting activity has been shown to depend on scientists' perception of the costs and benefits of patenting and thus their willingness to disclose inventions (Louis et al. 1989; Van Dierdonck et al. 1990; Blumenthal et al. 1996, 1997; Lee 1996, 2000; Campbell et al. 2000; Owen-Smith & Powell 2001a, 2001b; Thursby et al. 2001; Baldini et al. 2007; Gulbrandsen & Smeby 2005; Renault 2006; Bercovitz & Feldman 2008; Haeussler & Colyvas 2011). For example, in a study of entrepreneurial activity in 102 universities in 12 European countries, Guerrero et al. (2016) found that informal factors such as attitudes and role models were more important in shaping entrepreneurial activity than formal factors such as support measures, education and training.
Therefore, it is important to examine scientists' perspectives and other individual characteristics that may affect their decision about whether or not to engage in industry-oriented and commercial activities.

For example, Renault (2006) conducted interviews with 98 professors at 12 American universities and concluded that professors' propensity to engage in collaboration with industry, patenting and spinout formation was heavily influenced by the extent to which they believed that the dissemination of knowledge in the economy to be an important mission for universities.

Similarly, Owen-Smith and Powell (2001b) examined motivations for university patenting and concluded that researchers' beliefs about positive personal and professional outcomes of patenting their research impacted their likelihood to engage in patenting.

Tartari & Breschi (2012) also emphasized that the decision to engage with industry is shaped by the institutional environment and the individual researchers' perceptions of the potential costs and benefits; based on a large-scale survey of Italian university researchers, they found that the decision to collaborate is influence by researchers' perceptions of the threats to academic freedom posed by such collaboration.

Based on a survey of life science researchers in Denmark, Davis et al. (2011) found that a substantial proportion of scientists were skeptical about the impact of university patenting on traditional academic norms. More precisely, 27 pct. of respondents believed that patenting had a negative impact on academic freedom, i.e. the freedom to choose research agendas free of commercial interests, and 41% believed it had a negative impact on the norms of open science. The most skeptical respondents were scientists oriented towards basic research (particularly the less productive ones), recipients of research council grants, scientists with close relations to industry, and full professors. Highly productive scientists were less concerned. Their results suggest that university patenting policies will have different degrees of impact on staff behavior depending on prevalent perspectives among different subsets of researchers.

Moutinho et al. (2007) surveyed and interviewed Portuguese researchers in the life sciences and biotechnology and found, among other things, considerable variation in individual scientists' perceptions of the impact of commercially-oriented activities on university research. However, respondents generally perceived the personal benefits to be derived were relatively low, while the level of difficulty was perceived as high and the degree of support from the research organization to be low.

Lam (2011) found that some scientists are intrinsically motivated not just to engage in curiosity-driven research but also to satisfy their curiosity and/or a desire to contribute through society by engaging in collaboration and commercialization activities. Thus, commitment to core scientific values can coexist alongside motivations to engage in commercially-oriented activities. On a related note, Lam (2015) argued that the conventional assumption that scientists are motivated by intrinsic satisfaction and reputational awards while commercial activities are driven by the desire for financial represents a false dichotomy and simplistic view of human motivation; she argued that scientists are driven by a wide variety of different types and combinations of motivational factors.

Freitas & Nuvolari (2012) argued that scientists' motivations to engage in patenting is linked to different roles of industry partners in proposing, financing and performing specific research projects. However, even positive attitudes towards industry-oriented or commercial activities are no guarantee that such activities will emerge. For example, the aforementioned study by Moutinho et al. (2007) showed that even though most had no ethical objections to disclosing their inventions or to the commercial exploitation thereof, yet the respondents showed a low propensity to engage in patenting and licensing. The authors suggest that this may be explained by the aforementioned finding that scientists generally believed the personal benefits from such activities to be low, and the level of difficulty to be high.

On a related note, based on inputs from focus groups consisting of academic researchers, de Jong et al. (2016) found that there was a gap between perceptions in policy and science. The authors looked specifically at how policymakers and academic researchers perceived the notion of "impact": even though policy documents convey a broad definition of the impact of research, scientists perceive policymakers as being too narrowly focused on *commercial* impacts.

THE ROLE OF OTHER INDIVIDUAL CHARACTERISTICS

A number of other individual characteristics have been shown to matter for researchers' collaboration and commercialization activities.

Prior experience with entrepreneurship or industry. Unsurprisingly, perhaps, researchers who have personal experience in starting a business or who are closely related to entrepreneurs are more likely to start a new firm

(Klofsten & Jones-Evans 2000; Shane & Khurana 2003; Abreu & Grinevich 2013).

Similarly, researchers who have been employed in industry (for a substantial part of their career) are likely to have both more industry funding and higher patent productivity than colleagues without such experience (Dietz & Bozeman 2005; Abreu & Grinevich 2013).

Research also shows that academic researchers with a record of past interaction are more likely to be involved in a greater variety of interactions with industry, and also to engage more frequently across a wider set of interaction channels (D'Este & Patel 2007).

Why does experience matter? For one, many scientists lack knowledge of the possible applications of their research (Hellman 2005), particularly when that research is very fundamental in nature and may therefore have multiple and diverse applications. Insight into particular industries or firms increases the likelihood that academic scientists will be able to see potential uses or users of their research.

Orientation towards collaboration. On a related note, Kalar & Antoncic (2015) found that individual researchers' orientation, desire, and willingness to work with others is positively and significantly related to their engagement in technology and knowledge transfer. He authors argue that an overall orientation towards teamwork stimulates the desires to participate in interdisciplinary projects with industry.

Age and/or academic position. Generally speaking, academic studies indicate that participation in industry collaboration and possibly also commercialization activities increase with age and/or seniority (see e.g. Levin & Stephan 1991; Carayol 2007; Link et al. 2007; Stephan et al. 2007; Abreu & Grinevich 2013). This is likely explained by the pressure on younger researchers to demonstrate their academic worth and to build a strong publication list; in contrast, more established academics are likely to have both more time to engage with the non-academic community (Abreu & Grinevich 2013). They are also likely to have better personal networks to companies and other non-academic actors, which increases the likelihood of engaging in collaboration and commercialization activities (Link et al. 2007; Fini et al. 2010).

How else might age matter for scientists' interaction with non-academic actors? In a review of prior research on the importance of researchers' age, Stephan (1996) concluded that age is weakly but inversely related to research productivity and the acceptance of new ideas, suggesting that older researchers are generally speaking less active and more close-minded. This close-mindedness is likely to apply also to increasing expectations or demand of researchers to engage in collaboration or commercialization activities; indeed, Davis et al. (2011) found that older scientists were more skeptical towards patenting in university, possibly because their norms and expectations were shaped at a time when the focus on external collaboration and commercialization of university research results was lower.

On a related note, D'Este & Patel (2007) found that age had a negative impact on the variety of collaboration mechanisms that researchers engage in, while academic position was associated with a higher degree of variety. This suggests that when age and career advancement do not move hand in hand, academic position is more important in understanding the propensity of researchers to engage with the non-academic world.

International mobility. Krabel et al. (2012) examined whether scientists employed in foreign countries and foreign-educated native researchers are more ‘‘entrepreneurial'' than their ‘‘domestic'' counterparts. Based on data from researchers at the Max Planck Society in Germany, they found that academic entrepreneurship can indeed be stimulated by facilitating the mobility of scientists across countries, and suggest this may be explained by foreign-born and foreign-educated scientists possessing broader scientific skills and social capital, which increases the likelihood that they will start a company. On a related note, Wright (2014) argued that scientists may specifically choose to move to universities and ecosystems that are more conducive to their research and their efforts to commercialize that research.

Gender. Several studies indicate that male researchers are more likely than their female counterparts to engage in commercialization activities and in collaboration with industry, even when controlling for seniority and scientific discipline (e.g. Thursby & Thursby 2005; Whittington & Smith-Doerr 2005; Ding et al. 2006; Link et al. 2007; Abreu & Grinevich 2013; Tartari & Salter 2015). Some of the possible explanations that have been put forth in the literature include that women carry a heavier workload at home, are less likely to have industry experience and network relations to firms, and may be more risk averse than male researchers (Ding et al. 2006; Stephan & El-Ganainy 2007)

However, based on a large scale study of UK physical and engineering scientists, Tartari & Salter (2015) argued that gender differences in collaboration activity can be tempered by the social context in which female scientists work, notably by factors such as the presence of women in the local work setting and/or the scientific discipline and institutional support for women scientists' careers.

Colyvas et al. (2012) questioned the assertion that female scientists are less involved in formal technology transfer and highlighted previous research showing that gender differences disappear when personal characteristics and resources are included as variables in the analysis (Xie & Shauman 2003). Based on a study of US medical school data, Colyvas et al. (2012) found no significant gender differences in the likelihood of reporting inventions or successfully commercializing them, though women in their study tended to disclose fewer inventions than male scientists. They argued that these finding may indicate that female scientists are an untapped source of entrepreneurial talent.

Ultimately, the question of whether and, if so, to what extent male and female scientists differ in their research collaboration "does not lend itself to a straightforward answer" (Bozeman & Gaughan 2011, p. 1393). Bozeman & Gaughan (2011) pointed out that many gender-correlated variables could mitigate the relationship between gender and collaboration. For example, they argued, gender-correlated differences in the number of collaborators could be explained either by something intrinsic to men's and women's work strategies and preferences or to their different positions in work structures and hierarchies. The authors examined questionnaire data from the US National Survey of Academic Scientists and found, counter to prior research, that in a model that takes into account such factors as tenure, discipline, family status and doctoral cohort, women actually have somewhat more collaborators on average than do men. Both male and female scientists with more industrial interactions and those who were affiliated with university research centers had more collaborators. However, Bozeman & Gaughan (ibid., p. 1393) also found that:

> ***Men and women differ in their collaborator choice strategies. Men are more likely to be oriented to "instrumental," and "experience" strategies, while both men and women are motivated by "mentoring" strategies.***

All in all, many studies underline the importance of individual attitudes and decisions in shaping university-industry interactions. Perkmann et al. (2013, p. 433) therefore call for increased attention to the individual researcher:

> ***As individual discretion seems the main determinant of academic engagement with in-***

dustry, policy measures should address individuals, in addition to influencing university practices and structures. For instance, fostering individual-level engagement skills would appear to be a potentially powerful lever, not only for increasing the volume of university–industry relations but also their quality. In this respect, policy should not implicitly assume that 'more is better' but seek to differentiate the conditions under which engagement generates both academic and industrial benefits, so minimise the risk of failure.

HOW IMPORTANT ARE FINANCIAL INCENTIVES?

A number of the incentive mechanisms aimed at stimulating researchers to engage in collaboration and especially commercialization of their research are based on financial rewards. This includes for example many universities' policies for sharing royalties from licensing of university-owned patents with the researchers listed as inventors on the patents (e.g. Bercovitz & Feldman 2008; D'Este and Perkmann 2011).

Such incentives are based on an assumption that academic researchers are motivated by financial rewards tied to collaboration and commercialization activities (Jensen & Thursby 2001; Link & Siegel 2005; Lach & Schankerman 2008).

Owen-Smith & Powell (2001b) found that the higher potential monetary value of university patents in the life sciences leads (at least some) researchers to engage in patenting with a view to increasing their income, while the lower pay-off from patents in the physical sciences means that researchers who engage in patenting do so for other reasons, notably to develop relationships with firms, access equipment or exploit other research-related opportunities.

In a study of researchers from 67 institutes of the German Max Planck Society, Göktepe-Hulten & Mahagaonkar (2009) found that engagement in patenting not was motivated not by a desire to generate personal income but rather to signal achievements and strengthen reputation among both academic peers and industry stakeholders. Similar findings have been presented in e.g. Baldini et al. (2007) and Azagra-Caro et al. (2008). The latter study found that academic researchers are motivated to collaborate with industry not by the prospect of increasing their income but rather by non-monetary incentives, which – perhaps unfortunately for university managers and policymakers – are harder to cater to. Similarly, D'Este & Perkmann (2011) conclude that managers and policymakers should refrain from relying on monetary incentives to promote engagement and instead consider how to stimulate other incentives among academic researchers.

Moreover, as we will see in chapter 6, for most universities and researchers, there is relatively little money to be made from patenting of university research results. This holds true even for entrepreneurial activities: Åsterbro et al. (2013) examined total earnings for the universe of 478 individuals working at Swedish universities who quit to become full-time entrepreneurs between 1999 and 2008. They found entrepreneurship to be a gradual process and episodic for academics. Moreover, their earnings were similar before and after becoming an entrepreneur, and there were no dividends and capital gains to speak of. In view of the fact that the income risk is more than three times higher in entrepreneurship, financial incentives are clearly not a good motivation for academic entrepreneurship.

FROM INDIVIDUAL RESEARCHERS TO RESEARCH GROUPS

As described above, individual researchers' motivations, experience and characteristics are important to understanding their interaction with industry. Many researchers, however, particularly in the wet sciences, work mostly in groups, and the research group or laboratory is therefore also an important unit of study (e.g. Larédo & Mustar 2000; Etzkowitz 2003; Lee & Bozeman 2005; Braam & van den Besselaar 2010).

Ramos-Vielba et al. (2015) examines motivations and perceptions of risks that influence the collaborative behavior of scientific research groups. They surveyed leaders of research groups in Spanish public sector research organizations and found that an overwhelming majority of groups engage in cooperation with both private firms and government institutions. Motivations were similar to those identified for individual researchers, with the key stated motivation for collaboration being to apply their scientific knowledge and discoveries.

Individual researchers' position *within* a research group can also matter for their participating in engagement and entrepreneurial activites.

For instance, Boehm & Hogan (2014) draw attention to the role of the principal investigator, or PI, in driving collaborations with industry, which is little studied. The authors found that PIs play a lead role in establishing and managing these complex multi-stakeholder research projects, and that they have to be 'jacks of all trades', able to take on the roles of project manager, negotiator, resource acquirer as well as traditional academic roles of Ph.D. supervision and mentoring. The authors concluded by suggesting that PIs are often better placed than TTO managers to function as boundary spanners between academia and industry and should therefore be considered explicitly in university policies and strategies for collaboration with firms. Casati & Genet (2014) also examined principal investigators, focusing on their practices and role in driving academic entrepreneurship.

A handful of studies look specifically at younger researchers, i.e. PhD students and postdocs. These studies are particularly relevant in view of the massive increase in the number of young researchers trained in academia these years, on an international level but also in Denmark.

Most studies of universities' collaboration with industry focus implicitly or explicitly on faculty members; however, as universities become ever more dependent upon external funding and participate in growing levels of collaboration with industry, increasingly, PhD students' research is tied more or less directly tied to supervisors' grants, which often involve industry collaborators (Thune 2010; Lee & Miozzo 2015). In fact, doctoral or post-doctoral students often directly conduct much of the research involved in collaborative research projects as part of their training (ibid.).

Lee & Miozzo (2015) examined how working on university-industry collaborative projects affects science and engineering doctorates' careers at the University of Manchester. They found that projects with industrial involvement are associated with higher degree of socialisation with industry and, not surprisingly, give the PhD candidates an advantage compared to PhD students from purely academic projects in terms of building a career in the private sector. This is in line with prior findings (e.g. Mangematin 2000). However, the authors also found some indications that engaging in projects with industrial involvement can have a negative effect on careers in public science.

Moreover, Lee & Miozzo (2015) found that collaborative projects were more likely to focus on solving firm-specific technical problems or developing firm-specific specifications/prototypes, rather than exploring high-risk concepts or generating knowledge in the subject areas. This implied that the projects resulted in fewer publications in scientific journals, which can negatively impact PhD graduates' chances of securing an academic position. However, the authors acknowledge that their study is based on a small sample from a single university, implying that the results should be treated with caution.

In contrast, Salimi et al. (2015a) compared the performance of collaborative and non-collaborative Ph.D. projects using data on 448 Ph.D. projects at Eindhoven University of Technology. They found that collaborative Ph.D. projects outperformed non-collaborative Ph.D. projects both in terms of industrial performance (as indicated by the number of patents and patent citations) and academic performance (as indicated by the number of publications and publication citations). However, these high performing projects were driven specifically by the university's collaborations with Philips and with public research organisations. Moreover, when the authors measured academic performance in terms of top-publications only, collaborative Ph.D. projects no longer outperformed the non-collaborative Ph.D. projects.

In a publication by the same authors, Salimi et al. (2015b) investigated how collaborative Ph.D. projects are governed, which is interesting as it influences decision-making, day-to-day management and disclosure policies in the project and thus, ultimately, the performance of the project and its likely impact on the careers of participating doctoral students. Prior research shows that shared governance modes, characterized by joint management and decision making, tend to have higher success rates than projects where governance is centralized with one of the parties. However, Salimi et al. (2015b) find that in more than two thirds of the joint Ph.D. projects they investigated, there was centralized rather than shared governance. They also found that geographical and/or cognitive distance makes a centralized governance mode more likely, and that the partner controlling critical resources tends to centralize governance. Finally, Salimi et al. (2016) identified several success factors in university-industry PhD projects, for instance in relation the choice of university supervisor and whether or not there is joint decision-making by both university and partner.

KEY MOTIVATIONS FOR COLLABORATION OR COMMERCIALIZATION

A survey of the literature indicates that academic researchers' who engage in industry-oriented activities primarily do so because they expect to realize benefits for their research and/or teaching activities. Key motivations to collaborate with firms or engage in patenting are the desire to access additional research funding, enhance their visibility, reputation or academic position, develop new or stronger relationships to firms, to access industry knowledge or valuable equipment or research materials, to demonstrate the value of their research, to test the practical applications of their research, or to access contacts or insight for use in their teaching (Meyer-Krahmer & Schmoch 1998; Lee 2000; Owen-Smith & Powell 2001b; Baldini et al. 2007; Lam 2007; O'Gorman et al. 2008; Welsh et al. 2008; Yusuf 2008; Fini et al. 2009; Göktepe-Hulten & Mahagaonkar 2009; Hayter 2015).

Based on a factor analysis of responses from a survey among UK academics in the physical and engineering sciences, D'Este & Perkmann (2011) distinguished between four main motivations for engaging with industry:

- **Commercialization**, that is, commercial exploitation of knowledge or research.
- **Learning** that can inform academic research e.g. through insight into R&D activities and problems in industry, feedback from industry, and inputs to increasing the

applicability of academic research. Such learning does not typically result directly in new scientific output but may contribute indirectly by pointing to interesting research problems and avenues for research or by providing insight into new industrial applications (Perkmann & Walsh 2009). D'Este & Perkmann (2011) argued that these benefits are likely to arise from backward links from application of technology and technological problem-solving that take places in industry, and which can provide valuable inputs more fundamental research agendas (see e.g. Rosenberg 1982, 1994a, 1994b; Brooks 1994; Klevorick et al. 1995).

- **Access to in-kind resources** e.g. industry-provided research expertise, equipment or materials.
- **Access to funding**, which may enable greater critical mass in the research unit and thus economies of scale, or contribute to the retention of staff (D'Este & Perkmann 2011), as many academic staff members are employed on short-term, externally funded contracts. Funding may come either directly from private sources or from public sources (e.g. as co-funding for collaborative projects) or from patent sale/licensing (Ankrah et al. 2013).

D'Este & Perkmann's (ibid.) findings confirm that the majority of academic engage with industry in order to further their own research. The commercialization motive was, on average, ranked lowest by respondents in their study.

The authors also found that different motivations drive different types of engagement or, put differently, that academic researchers' motivations differ depending on which mechanism for interacting for industry that they engage in. More precisely, researchers that were motivated by learning engaged more frequently in collaboration (that is, joint research, contract research and consulting). In contrast, and unsurprisingly perhaps, researchers motivated by commercialization aims were more likely to participate in patenting, spinout formation and consulting. The authors do stress, however, that their conclusions should be seen in light of the fact that their findings are based on survey responses from faculty in the engineering and physical sciences only, and not e.g. from the life sciences, which are known to have extensive collaboration with industry. Nonetheless, D'Este & Perkmann (2011) suggest there may be a tension between commercialization and research-related motivations, except in the provision of consulting services, where commercial and research-related motivations appear to co-exist.

Finally, on a related note, Lee (2000) found that benefits experienced by researchers in relation to research support, teaching, and entrepreneurial opportunity increase with the duration of the collaborative project, with projects spanning at least 3 to 5 years offering the greatest benefits; moreover, these longer projects were typically sponsored by large firms or a consortium of firms of mixed size. Lee (ibid.) also found that the level of benefits that accrue to academic researchers are related to the frequency of their interaction with collaborative partners, stressing the importance of e.g. frequent meetings and having staff spend extended periods of time in the lab of project partners.

THE EXTENT OF UNIVERSITY-INDUSTRY TIES IN DENMARK

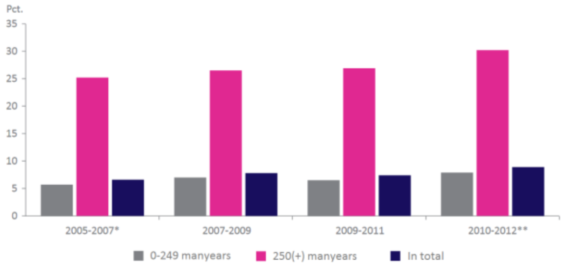
Like other countries, Denmark has seen a large increase in the volume of collaborative arrangements between public research organizations and industry. This increase is documented in a recent government-commissioned evaluation of knowledge exchange in Denmark (Styrelsen for Forskning og Innovation 2014). This evaluation concludes, among other things, that the past seven to eight years have witnessed high growth in the volume of research and development projects undertaken in collaboration between universities and firms, and that the overall volume of collaborative research exceeds the average volume for OECD countries. These collaborations are driven in particular by the Technical University of Denmark (DTU) and Aalborg University (AAU), but are widespread in all universities and disciplines.

The evaluation also concludes that there has been a "substantial" increase in the proportion of innovative Danish firms that collaborate with universities. However, it is debatable whether an increase from 7 pct. in the period 2005-2007 to 9 pct. in 2010-2012 can be described as a "substantial" increase (cf. figure 3). Generally speaking, few firms have the necessary and sufficient preconditions to engage in formal collaboration with universities (Belderbos et al. 2004; Bruneel et al. 2010). This is because such collaboration requires significant resources, a high level of absorptive capacity in the firm (e.g. Cohen & Levinthal 1990; Cockburn & Henderson 1998), and the ability to identify adequate partners in academia, which for many firms is very difficult (Mindruta 2013).

There has also been a significant increase in university patenting, technology transfer and entrepreneurship since the Act on Inventions at Public Research Institutions came into force in 2000. However, the evaluators (ibid.). concluded that the development in these activities has stagnated since the middle of the 2000s (cf. figure 4),[11] and that Denmark's performance on relevant indicators – particularly the foundation of new research-based firms – is modest compared to other countries, e.g. compared to Great Britain, Ireland and Switzerland.

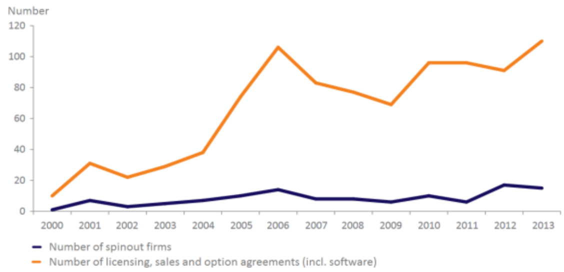
More detailed data on trends in knowledge exchange from public research organizations in Denmark is available from the yearly publication "Kommercialiseringsstatistikken" (Styrelsen for Forskning og Innovation 2015a).

Figure 3. Firms with innovation-related collaboration with institutions of higher education, as a percentage of all innovative firms in Denmark



Source: Styrelsen for Forskning og Innovation (2014). The figure was developed by IRIS Group based on data from Statistics Denmark. Notes from the authors of the figure: * 2005-2007 includes collaboration with "other public research institutions", incl. government laboratories; ** 2010-2012 are based on preliminary data. Surveyed firms are asked to indicate their collaboration behavior in the three years leading up to the time of the survey, which explains the overall in the last two periods in the figure.

Figure 4. Technology transfers from Danish universities during the period 2000-2013, in absolute numbers



Source: Styrelsen for Forskning og Innovation (2014).

MOTIVATIONS FOR AND IMPACT OF COLLABORATION ACCORDING TO DANISH RESEARCHERS

As mentioned in chapter 2, DEA (2014a) undertook a survey of Danish university researchers' participation in commercialization activities and

[11] It should be mentioned that patent applications by universities and university spinoffs appear to be stagnating or even showing a slight negative growth across OECD countries (OECD 2013).

their collaboration with non-academic actors in both the private and public sectors.

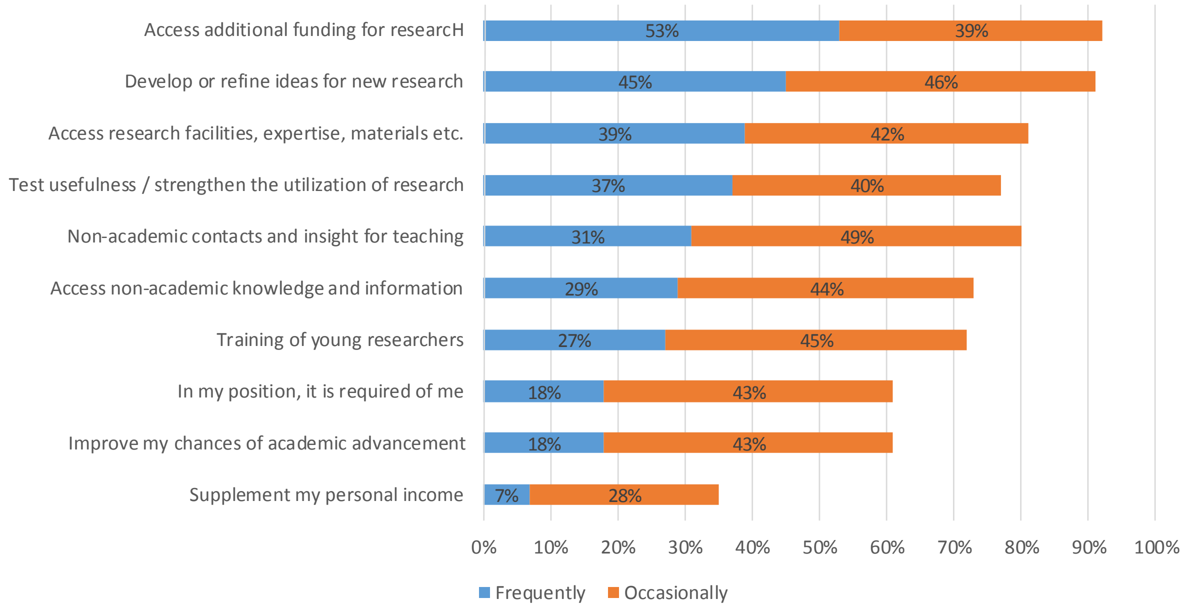
In line with international findings from academic research, the results of the survey indicate that academic researchers who engage in collaboration and commercialization of research do so primarily because they expect that this will benefit their research and, to a lesser extent, teaching activities. As apparent in figure 5, the most important motivations for non-academic collaboration were to gain access to funding, ideas and other resources for research (e.g. access to specialized research facilities, expertise, materials etc.), and to test or strengthen the usefulness of their research. Factors such as improving chances of career advancement, living up to expectations from management and achieving personal financial gain were the least important in motivating researchers to engage with non-academic collaborators. Again, these findings confirm the general perception that academic researchers eschew monetary gains for the ability to pursue their academic research aims.

The survey results also revealed substantial differences in the motivations for engaging in non-academic collaboration across universities and scientific disciplines. For example, researchers from the hard sciences were more highly motivated by the possibility of gaining additional funding or access to research facilities or materials than their peers from the soft sciences, presumably because of the significant costs associated with acquiring e.g. the scientific instruments, research materials and laboratory assistance often needed in the hard sciences.

The survey also examined the consequences of collaboration, as experienced by the researchers themselves, cf. figure 6. More than 70 pct. of the respondents indicated that engaging with the non-academic sector has a positive effect on the quality or scientific impact of their research and/or on the quality or relevance of their teaching activities. These findings suggest that there are significant complementarities between the traditional core missions of research and teaching on the one hand, and the so-called "third mission" activities on the other. More detailed analysis revealed that positive effects on research and teaching were, however, more strongly felt at some universities and in some disciplines than others. Further investigation is needed to explore why these differences exist.

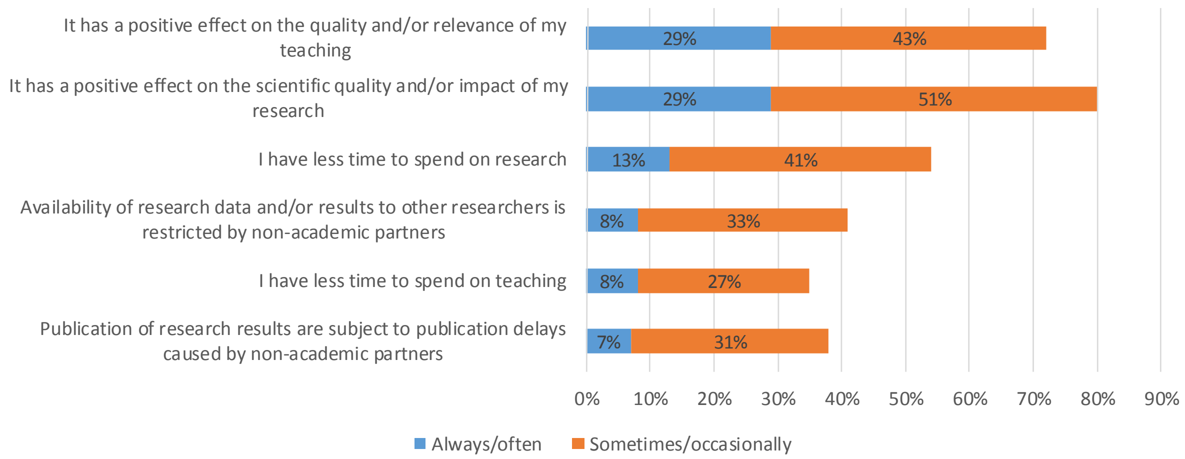
Moreover, while there is a relatively wide consensus among respondents as to the positive outcomes of non-academic engagement, there is much more variation in the extent to which individual researchers experience negative outcomes. About one in ten researchers "always or often" experiences negative outcomes such as reduced time to spend on research or teaching, publication delays, or restrictions on the availability of data or results to other researchers. Further analysis revealed that these negative consequences are not experienced by the same researchers, but rather that different researchers encounter different negative outcomes of collaboration. These findings should be seen in light of the academic literature on possible unintended negative effects on the dissemination of academic science, as discussed in chapter 2 of this report, and call for further investigation of the conditions under which collaboration and commercialization activities are associated with negative effects.

Figure 5. University researchers' motivation for engaging in commercial activities and with non-academic actors (2014 data)



Source: DEA (2014a). N.B.: Respondents who answered "never" or "don't know / not relevant" have been left out of the figure but are included in the number of observations. N(test) = 2,421; N(teaching) = 2,415; N(knowledge etc.) = 2,415; N(training) = 2,400; N(advancement) = 2,410; N(required) = 2,407; N(income) = 2,409.

Figure 6. Impact of engaging in commercial activities and with non-academic actors, as experienced by university researchers' participation (2014 data)



Source: DEA (2014a). N.B.: Respondents who answered "never" or "don't know / not relevant" have been left out of the figure but are included in the number of observations. N(test) = 2,421; N(teaching) = 2,415; N(knowledge etc.) = 2,415; N(training) = 2,400; N(advancement) = 2,410; N(required) = 2,407; N(income) = 2,409.

4. WHICH FIRMS COLLABORATE WITH ACADEMIA AND WHY?

WHEN AND WHY DO FIRMS ENGAGE IN R&D COLLABORATION?

As mentioned in chapter 1, recent years have witnessed a growing focus on the importance for firms of accessing external inputs to innovation and integrating them into in-house research and development activities (Chesbrough 2003). Collaboration is one of the key mechanisms by which firms access such external inputs; hiring new graduates or experienced staff is another.

When is collaboration for innovation relevant for firms to engage in? According to academic research, firms typically engage in collaboration on R&D when they are looking to undertake exploratory R&D (Bonesso et al. 2011) and/or to develop innovations that are more radical in the sense that they are not merely “new to the firm” but rather “new to the market” (Tether 2002).

Generally speaking, firms are also more likely to undertake R&D collaboration when they have high R&D intensity (Negassi 2004; Tether 2002) and therefore possess the “absorptive capacity” (Cohen & Levinthal 1989, 1990) necessary to benefit from close collaboration with external parties. As previously menitoned, some sectors are more likely to collaborate than others, particularly high tech and science-based sectors (e.g. Salter & Martin 2001).

Another important factor in firms’ decision to collaborate on R&D is whether or not they can secure the intellectual property rights to inventions that might be developed as a result of the collaboration, and thus appropriate potential future rents from their investment in the collaboration (Siegel et al. 2003b; Abramovsky et al. 2009; Cassiman & Veugelers 2002; Drechsler & Natter 2012).

Finally, some firms are open to collaboration because they lack the financial resources to fund their R&D activities (Drechsler & Natter 2012). Collaboration can provide direct or indirect access to financial and other resources in other organizations and, in some cases, to publicly funded grants for collaborative projects.

WHEN AND WHY DO FIRMS COLLABORATE WITH UNIVERSITIES?

We now turn our attention away from firms’ external collaboration on R&D in general, and their interaction with public research organizations in particular. The literature reveals a number of factors that influence firms’ propensity to collaborate specifically with public research organizations; these are outlined in the following.

It is relevant to note that firms are driven by different motives and therefore likely to enter into multiple collaborations that can meet different needs for the company (Broström 2012).

To engage in high-risk, long-term R&D. Firms may collaborate with public research organizations in order to explore R&D paths that are new to the firm, technologically more sophisticated and/or associated with a high degree of uncertainty (Lee 2000; Kaufmann & Tödtling 2001; Bercovitz & Feldman 2007; Tödtling et al. 2009; Hayton et al. 2010) and universities can help anticipate future research issues and translate the complex nature of the research (Hall et al. 2003).

Lee (2000) argued that firms may even engage in collaboration with academics to conduct ‘‘blue sky’’ research in search of new technology or even with no specific, immediate applications in mind. Indeed, private firms can have substantial incentives to invest in research, even basic research (Rosenberg 1990).

Moreover, the very choice to collaborate with academia can help insulate firms' R&D projects from the shifting priorities and resource constraints that many businesses operate under. Lacetera (2009) proposed that outsourcing a project to a university allows firm to commit not to terminate or alter it before completion, which can be valuable for firms looking to pursue scientifically valuable projects that may not hold economic value, at least in the short term.

To solve complex problems. When they wish to solve specific, complex technical problems that require highly specialized scientific or technological insight (Vincenti 1990; Lee 2000; Piga & Vivarelli 2004; Baba et al. 2009).

When the opportunity costs of collaborating with public science are low. When possibilities of securing IPR are already limited, for example if the technology is precompetitive, i.e. has a very low degree of maturity and is far from potential applications, because the early-stage nature and inherent uncertainty of the research process entails limited options for appropriability of research results (Panagopolous 2003), or if the firm is part of large R&D consortia with many partners (Link & Tassey 1989). In the latter case, IPR is already difficult to secure, and the opportunity costs of bringing public research institutions into the collaboration therefore are lower (Panagopolous 2003).

To generate variety in their knowledge base and thus increased innovation opportunities. Klevorick et al. (1995) argued that public science increases the number of scientific and technological inputs that firms can draw on in their endeavors to identify, combine and exploit new opportunities for innovation. They compared the role of science to "adding more balls to the lottery urn", thus increasing the chance that a firm will draw out "a winning ball".

But firms can also engage in collaboration with academia in order to actively contribute to the development of new opportunities. McKelvey et al. (2015) found that firms collaborate in order to increase the variety in the fundamental knowledge available for them to draw upon, rather than to form and exploit specific opportunities. The authors also found that large firms were more likely to seek to transfer this variety back to the firm as inputs to in-house opportunity creation, while smaller firms were more prone to using collaboration to create new opportunities in the market, particularly through networking with larger firms participating in the collaboration.

To maintain a relationship to the academic community. Firms may also collaborate with academia simply to stay abreast of new research, maintain a network to the university, gain access to the university's international research network, and to gain access to university graduates for recruitment purposes (Lee 2000; Broström 2012). Firms may even engage with universities as part of their HR strategy, to motivate or reward employees, e.g. those with a background in academia of their own (Broström 2012).

When they are larger. Firms' willingness and ability to do collaborate with public science may also depend on firm size. Large firms are more likely to collaborate with public research organizations than small firms. This has to do with the fact that large firms generally have more resources to invest in R&D activities that are not expected to generate results or financial returns in the short term (Fontana et al. 2006; Mohnen & Hoareau 2003; Negassi 2004). Small and medium sized companies generally operate under greater financial constraints (Czarnitzki et al. 2011; Hall & Lerner 2010) and therefore often choose to prioritize R&D projects and collaborations that are less risky and more likely to generate returns in the short term.

On a related note, Bruneel et al. (2015) pointed out that slack financial resources (which are often more likely in larger firms than in smaller businesses) can be an important factor in shaping companies' interactions with academia. More specifically, the authors found that firms with high levels of financial slack are more likely to engage in explorative knowledge sourcing, e.g. in order to explore new areas. When levels of slack are low, firms are however more likely to seek out collaboration for exploitative knowledge sourcing, i.e. with a view to immediate and practical gain.

When they are more open to external knowledge and technological inputs. Based on a data from a survey among innovating SMEs in seven EU countries, Fontana et al. (2006) find higher levels of collaboration with public research organizations among firms who, generally speaking are more willing to "search, screen and signal" their external environment for inputs to their R&D projects. This openness can take the form of e.g. screening publication databases, outsourcing R&D tasks, and patenting with a view to signal the firm's innovation competencies (thus voluntarily disclosing knowledge to potential collaboration partners, be they firms or public research organizations). In fact, some firms actively choose to disclose important in-house knowledge and information about their scientific and technical capabilities to external agents not just to attract potential partners but also in order to e.g. gain feedback, expand their networks or reputation, and promote higher order learning and knowledge (Penin 2005; Fontana et al. 2006).

On a related note, Laursen & Salter (2004) found that firms that have more "open" search strategies (as indicated by the number of external channels of information that they use) are more likely to value knowledge and innovation inputs from universities. Search is key to innovation, as a wide and diverse search strategy can help the firm create opportunities to access and integrate highly specialized knowledge sets (Laursen & Salter 2004). Science has been compared to a "map" that allows firms to navigate unchartered territories in their technological search by either leading them more directly to useful combinations, by eliminating fruitless paths of research, or by motivating them to continue even in the face of negative feedback (Fleming & Sorenson 2004).

However, research on firms' search processes related to innovation have focused mostly on where firms search for information rather than *how*, i.e. the processes by which they do so, suggesting the need for further research in this direction (Lopez-Vega et al. 2016), e.g. on how they identify and select collaboration partners, which is particularly interesting since firms are often unaware of which academic researchers and findings could be valuable in their product development and innovation efforts (Hellman 2005).

When they operate in high tech or science based sectors. As mentioned in chapter 1, industry sectors differ in their overall propensity to draw on university science as an input to their R&D and innovation-related activities (see e.g. Meyer-Krahmer and Schmoch 1998; Cohen et al. 2002; Schartinger et al. 2002; Thursby & Thursby 2011). Thursby & Thursby (2011) argue that part of the explanation herefor lies in that new technologies and new methods of inventing involve high degrees of tacit knowledge and the need to bring together highly specialized knowledge and competences, rendering collaboration a necessity. As new methods become codified or more routine, however, the importance of tacit knowledge and thus also the need for collaboration decrease.

Generally speaking, and unsurprisingly, companies are more likely to engage in external collaboration on R&D when they operate in science or technology driven sectors (Bayona et al. 2001; Dachs et al. 2008; Miotti & Sachwald 2003) and/or in sectors where technology is developing rapidly (Belderbos et al. 2004b).

These differences emerge because sectors differ in their sources and patterns of innovation and in the extent of the scientific and technological opportunity set (Pavitt 1984; Klevorick et al. 1995; Marsili 2001).

Collaboration with public research organizations is for instance common in sectors such as pharmaceuticals, ICT, food and space technology (Salter & Martin 2001), where much of the basis for innovation can be found in university labs and other public research organizations.

When they have some (but not too many) slack resources. Finally, Hayton et al. (2010) argued that firms are more likely to collaborate when they have some degree of slack resources, allowing them to "buffer" the firm in riskier innovative activities. If, however, firms have extensive slack resources, they are less likely to engage in collaborative R&D, presumably because they may then prefer to build up R&D competencies and activities in-house instead of relying on external partners (ibid.).

On a related note, firms' willingness and ability to do collaborate with public science may also depend on firm size. Large firms are more likely to collaborate with public research organizations than small firms. This has to do with the fact that large firms generally have more resources to invest in R&D activities that are not expected to generate results or financial returns in the short term (Fontana et al. 2006; Mohnen & Hoareau 2003; Negassi 2004). Small and medium sized companies generally operate under greater financial constraints (Czarnitzki et al. 2011; Hall & Lerner 2010) and therefore often choose to prioritize R&D projects and collaborations that are less risky and more likely to generate returns in the short term.
Similarly, Bruneel et al. (2015) pointed out that slack financial resources (which are often more likely in larger firms than in smaller businesses) can be an important factor in shaping companies' interactions with academia. More specifically, the authors found that firms with high levels of financial slack are more likely to engage in explorative knowledge sourcing, e.g. in order to explore new areas. When levels of slack are low, firms are however more likely to seek out collaboration for exploitative knowledge sourcing, i.e. with a view to immediate and practical gain.

Firms differ. Finally, firms will differ in how and why they collaborate with universities. Santoro & Chakrabarti (2001) identified three types of firms with different strategic motivations to engage with university-industry research centres: "collegial players" are typically large firms working with UIRCs on research topics of long-term, while "aggressive players" can be either small or large firms who engage with the centers primarily to develop and commercialize marketable products and services. Finally, "targeted players" are generally smaller firms looking for help in addressing specific needs and problems central to their business.

Finally, research has pointed out that the nature of firms' R&D objectives can shape the mechanisms of collaboration that they choose for engaging with academic researchers in specific projects. Based on a study of 52 projects carried out by a multinational company in the semiconductor industry, Cassiman et al. (2010) found that basic research projects are likely to be developed through formal cooperative agreements, and tend to be strategically less important to the firm; meanwhile, for strategically more important projects and for projects where the knowledge to be developed is particularly novel to the firm, the firms is more likely to use formal and more narrowly defined contracts.

DO PUBLIC SUBSIDIES MATTER FOR R&D COLLABORATION?

Mowery (1998) criticized a tendency to see publicly co-funded R&D collaboration "as a 'good thing' in and of itself" and argued that it should be seen as a means, not an end. He also underlined that

> ***Collaborative R&D can yield positive payoffs, but it is not without risks. Moreover, R&D collaboration covers a diverse array programs, projects, and institutional actors. No single recipe for project design, program policies, or evaluation applies to all of these disparate entities.***

But why do we provide public funding for collaborative R&D? The classic market failure argument for investing public funding in basic research (see Nelson 1959; Arrow 1962) has been extended to include public subsidies for R&D, in particular collaborative R&D projects involving firms and public research organizations (Cervantes 1998; Link & Tassey 1989; Martin & Scott 2000; Mowery 1998; Scott 1998; Tassey 1997, 2005). Essentially, the justification rests on the argument that the limited possibilities of appropriating (enough of) the returns to research and also some forms of development activities mean that firms will, from a societal perspective, underinvest in such activities in the absence of public intervention. See for example Mowery (1998) or Czarnitzki & Lopes-Bento (2012) for a discussion of rationales for public funding of collaborative R&D projects. More recently, such public grants have also been warranted based on the so-called “system failure” argument, that is, based on the need to remedy weaknesses or remove obstacles for interaction between key actors in the innovation system (e.g. Foray & Steinmueller 2003).

Prior research suggests that public grants can affect firms’ likelihood of engaging in collaborative R&D. For example, based on Spanish data, Gonzalez & Pazo (2008) found that public grants for collaborative R&D can have a significant impact on firms’ likelihood of engaging in R&D projects, particularly for smaller firms in low-tech sectors. On a related note, based on data from the Community Innovation Survey in seven European countries, Franco & Gussoni (2014) found that public subsidies have a positive impact om firms’ propensity to engage in R&D cooperation, and that subsidies seem particularly important to promote collaboration among firms in the service sector. A number of other studies find a positive relationship between receiving public subsidies and firms’ likelihood to engage in collaboration, e.g. Miotti & Sachwald (2003), Busom & Fernandez-Ribas (2008), Abramovsky et al. 2009 and Carboni (2012). Not all studies, however, find evidence of a significant impact of subsidies on R&D collaboration (see Belderbos et al. 2004a and Colombo et al. 2006).

Other research has indicated that receiving a public R&D grant can have an important signaling effect, effectively strengthening firms’ ability to attract long-term capital (Takalo & Tanayama 2010; Meuleman & De Maeseneire 2012).

A recent non-academic study of R&D-intensive Danish firms’ use of public research and innovation programs confirmed that public R&D grants can play an important role in allowing both smaller and large firms to pursue “high risk, high gain” projects with a longer time to market (DEA & DI 2014).

But do public grants generate the expected value? The aim of this type of public funding is to stimulate some form of “additionality”, that is, desirable behavior or outcomes that would not have occurred in the absence of that funding. If not, the public subsidy is said to crowd out private funding, i.e. acting effectively as a substitute rather than a catalyst.

The literature distinguishes between three main types of additionality effects, which are described briefly in the following.
Input additionality, which refers to additional investments in R&D that occur as the result of the public grant (Clarysse et al. 2009). Although the evidence is mixed (see e.g. David et al. 2000), there seems to be an emerging consensus that there is no crowding-out effect (Duguet 2004;

Czarnitzki & Licht 2005; Gonzalez & Pazo 2008; Clarysse et al. 2009). Input additionality is the easiest of the three types of additionality effects to measure. However, as Clarysse et al. (2009) pointed out, an important shortcoming of the concept of input additionality is that innovation is not linear (Kline & Rosenberg 1986); as no direct relationship can be made between innovation inputs and outputs, it can be questioned whether input additionality is associated with increased innovation or value for society.

Output additionality, which refers to the proportion of outputs from R&D that would not have been produced in the absence of public funding (Georghiou 2002). Outputs include direct results such as patents, scientific publications, prototypes and even PhD graduates, as well as indirect outcomes such as new scientific or technological applications, new products, and increased revenue, value added or productivity (Klette et al. 2000; Clarysse et al. 2009). Output additionality is difficult to estimate, particularly for indirect outcomes (Clarysse et al. 2009). Several studies find evidence of output additionality from public R&D grants, but their validity has been questioned (see e.g. Klette 2000; Dimos & Pugh 2016).

Behavioral additionality, which refers to changes in processes and behavior within the firm, which may lead to input and/or output additionality in the long term (Buisseret et al. 1995; Georghiou 2002; Falk 2007). This type of additionality has therefore also been referred to as "second-order additionalities" (Autio et al. 2008) and recognizes that participation in publicly funded R&D projects can catalyze not just short-term results but also more deep-rooted and long-term changes in behavior.

It has been suggested that behavioral additionality may emerge as a result of new contacts established in connection with publicly funded R&D projects or of learning by participating firms. For example, using survey data from Belgian recipients of R&D grants and a matched sample of innovative firms, Clarysse et al. (2009) found a positive relationship between behavioral additionality and congenital and interorganizational learning; these learning effects, however, decreased with the number of subsidized projects that firms entered into.

Recent work also points to other factors that can affect the extent to which firms realize additionality effects. Wanzenböck et al. (2013) found that R&D-related firm characteristics influence the realization of behavioral additionality. More precisely, they found using data from Austrian firms, that R&D-intensive firms are *less* likely to attain behavioural additionalities, while small, young and technologically specialised firms are *more* likely to do so, providing an argument for shifting the focus of public support towards smaller, specialised firms with lower R&D experience.

On a related note, Clausen (2009) showed that different types of grants are likely to generate different types of additionalities: while "research" subsidies are likely to stimulate R&D spending by firms, "development" subsidies appear to substitute such spending. This finding suggests that public programs should be focused on research projects rather than development projects in order to stimulate more R&D.

Obviously, additionality effects are difficult to document, among other things because it can be difficult or impossible to establish an appropriate counterfactual (Clarysse et al. 2009) and due to problems connected to selection bias (David et al. 2000). Luukkonen (2000) pointed to a number of issues in the assessment of additionality in evaluation of R&D programs and suggested that the system of evaluation (for EU framework programs) rewards short-term success.

Nonetheless, a substantial number of studies have examined the effects of public subsidies. Among more recent examples, Czarnitzki & Lopes-Bento (2013) evaluated grants from IWT, an innovation agency in Flanders. They documented positive effects on R&D investments by participating firms, even when firms received funding repeatedly and if the projects also received financial support from other sources. They also concluded that each subsidized project, on average, created or secured five R&D jobs in the Flemish economy.

Czarnitzki & Hottenrott (2010) presented similar conclusions and stressed that public intervention should therefore be targeted towards firms that experience real and substantial constraints, and towards those projects that are characterized by the largest gaps between private investors financial incentives to invest in research and development on the one hand and society's interest in ensuring adequate funding for innovation on the other. The authors argued that the firms most likely to experience such constraints – and therefore the best candidates for public intervention – are (a) small and medium sized enterprises, (b) new firms and startup companies with a high capacity for innovation, (c) in fundamental research (as opposed to routine R&D or development projects), and (d) firms that operate in markets where there is not a well-functioning venture capital market.

As previously mentioned, the evidence on additionality effects of public funding for R&D are mixed (see e.g. Franco & Gussoni 2014). Prior work is reviewed in several studies e.g. by Cerulli (2010) and, most recently, Dimos & Pugh (2016) who conclude that there is no conclusive evidence that public R&D subsidies crowd out private investment; however, they also fail to find evidence of substantial additionality.

Why aren't these studies showing better results? Part of the explanation could lie in the heterogeneity of these public schemes and the lack of solid, systematic evaluations across different schemes (Mowery 1998). Most evaluations have a relatively short-term focus, driven by current political agendas and focusing on input and output additionality, rather than on identifying longer-term learning and innovation effects; this may lead to an underestimation of these effects and, in turn, underinvestment in R&D instruments (Roper & Hewitt-Dundas 2014). Also, there appears to be substantial variation in project performance; many projects simply aren't as well designed or managed as they could or should be (DEA & DI 2014), leading public schemes to show a high degree of variation in their results. However, relatively little is known about the management practices used in university-industry collaborative research (Morandi 2013), suggesting this could be a fruitful avenue for further research.

Several studies have nonetheless found evidence of a positive relationship between participating in publicly funded collaborative R&D projects and participating firms' innovative activities and performance have been fairly well established in the literature (see e.g**.** Hagedoorn et al. 2000, Link et al. 2002, Busom 2000, Wallsten (2000), Almus & Czarnitzki 2003, Czarnitzki et al. 2007).

A recent study by Spanos et al. (2015) found that firms who participated in publicly funded collaborative R&D projects under the fifth and sixth framework program of the EU found, however, that certain factors affect the likelihood of a project leading to significant gains in terms of innovation, including whether the project built on past R&D activities and the participating firm's prior R&D experience and integrative capabilities, both of which are associated with its absorptive capacity. Other factors that were found to increase the likelihood of a project leading to innovation in a participating firm were large consortium size, long project duration, familiarity with partners in the consortium, and project idea originating from industry (as opposed to academia).

Finally, on a Danish note, Chai & Shih (2016) examined the impact of grants from the (now closed) Danish National Advanced Technology

Foundation. They found that funding was associated with, among other things, an increase in the number of patents granted for up to 4 years after funding for both young firms and for firms participating in larger projects, and that firms experienced increased academic collaboration as indicated by cross-institutional publications subsequently to receiving funding. The authors argued that their results indicate that government *can* motivate firms to engage in research which is more fundamental in nature while at the same time retaining applicability to problems and goals in industrial R&D.

INSIGHT FROM DANISH FIRMS' PARTICIPATION IN PUBLICLY FUNDED R&D COLLABORATION

The findings from the scientific literature are in line with a recent non-academic survey and interview-based study of R&D intensive firms' in Denmark and their participating in publicly funded programs to stimulate public-private collaboration on research and innovation (DEA & DI 2014). Respondents included firms from all major R&D-intensive sectors, including the pharmaceutical sector which, as mentioned in chapter 1, dominates private investments in R&D in Denmark.

More precisely, the respondents' main motivations to engage in such programs were, first, to strengthen their opportunities for developing innovation. Large businesses were slightly more focused than small and medium sized enterprises (SMEs) on getting access to knowledge and technology that may lead to innovation and competitive advantage in the long term. In contrast, SMEs were more focused on gaining knowledge, methods or technology that may be translated into new products and increased sales in the short term. This is unsurprising of the aforementioned fact that small businesses often operate with limited R&D budgets and are more under pressure to show the results of their investments in R&D. Second, respondents were motivated by the opportunity to carry out larger, more ambitious projects. Most companies, even the largest and most R&D-intensive, have limited resources for research and development activities. Moreover, the lion's share of their resources is typically allocated to short-term development projects that are close to the market. Another key reason why respondent companies choose to participate in publicly funded RDI projects is therefore that it gives them the opportunity to carry out more, larger and more ambitious projects than they are able to undertake on their own. The public gearing of firms' investments allows companies can invest in more long-term and uncertain projects, from which revolutionary breakthroughs can potentially emerge.

As such, it is not surprising that the firms that contributed to the study typically did not expect their collaborations with public research organizations to result in market-ready products. Rather, companies see innovation as something that happens within in the company – after the project. The results of an RDI collaboration often follow an unpredictable and uncertain road before they are translated into innovation, and companies do not expect to see a prototype or an end-product before at least one and sometimes as much as fifteen years after the project has ended. According to firms, a good result of a project does not have to be a product prototype, but might just as well be new knowledge, a workable component, a new method or even just the opportunity to test a technology or an idea.

In line with international, academic research findings, the DEA & DI (2014) study also showed that Danish firms were motivated to engage in publicly co-funded R&D collaborations by a number of other, less significant factors including

- Being able to establish stronger collaborations with university researchers,
- Keeping their company updated on developments on the research front,

- Motivating staff with an academic background,
- Gaining access to students or researchers with a view to recruitment,
- Supporting the development of relevant research and education environments in their field, by helping them access public funding for specific projects, and
- Strengthening the company's reputation as an R&D-intensive, innovative business.

Moreover, results of the study indicated that firms choose different types of collaborative arrangements depending on the aims of the collaboration. For example, many were reluctant to place technology or product development activities in large consortia or projects with multiple partners. In line with findings from previously mentioned academic studies (Link & Tassey 1989; Panagopolous 2003), firms were concerned about their ability to appropriate the results of the projects. They were also wary of the effect that many partners with varying degrees of commitment and contribution to the project, along with high levels of complexity and coordination costs, can have on the overall progress and achievements of a collaborative venture. In addition, several firms pointed out that the sheer scale of large consortia with large grants and budgets have a high degree of visibility, giving participants incentive to "play it safe" rather than take risks with an innovative project.
Large consortia are therefore typically reserved for projects of a precompetitive nature, or if there is a need to bring actors together in a way that the companies themselves are not able to do. For example, it may be relevant to gather competing firms or various actors within the same value chain. Likewise, large consortia were described as a useful tool for working with the development of legislation and standards. On a similar note, Vonortas & Spivack (2006) concluded based on a study of Advanced Technology Program's Information Infrastructure for Healthcare program in the US that large research partnerships with diverse members are more appropriate for early stage technologies and to create standards.

For concrete technology or development projects, respondents preferred designing more focused partnerships with fewer objectives and carefully selected partners. Such projects seek, for instance, to generate specific knowledge, solve recognized problems or to test promising materials or technologies. Their goals are usually some form of concrete contribution to an innovation process. Partners are, at least ideally, selected based solely on their ability to contribute to the success of the project, and not e.g. because of prior collaboration or to accommodate the wishes or demands of those organizations who provide funding for the project.

According to the companies interviewed, inclusion of activities or partners that are neither "natural" to the project nor highly committed may result in an "artificial" or even "schizophrenic" project with insufficient focus or momentum – which in turn is likely to reduce the company's interest and commitment in the collaboration.

WHAT DO WE KNOW FROM RECENT DANISH EVALUATIONS?

Evaluations and studies of Danish policy instruments are undertaken regularly. By far the majority of these studies are commissioned by government authorities or the funding bodies that are responsible for the administration of the instruments. They are usually undertaken by external consultants, mostly from the private sector, and sometimes involve evaluation panels consisting of relevant experts from Denmark and abroad.

It is beyond the scope of this study to undertake an in-depth review of the body of evaluations and analysis of Danish research and innovation funding organizations. However, we will attempt to draw out some key, general insights from evaluations from the past ten years. The analyses that have been included in this review are listed in box 2.

We will refrain, however, from drawing any overarching conclusions about the effectiveness of public funding instruments based on the existing body of analyses. This can be explained by three key shortcomings of this type of evaluation (Mowery 1998; Arnold 2004; Veugelers 2014). First, most evaluations are focused on one or few programs or instruments, not on systems of complementary or overlapping programs or instruments.

Second, evaluations are often designed to answer relatively narrow questions from policymakers and politicians, typically related to those specific programs or instruments.

Finally, evaluations often use tools and methods designed to support intervention at the program or even program level, and not the system level.

A synthesis of other key, selected insights from recent evaluations of publicly funded research and innovation programs in Denmark are presented briefly in the following. Please note that this is but a small excerpt of the many findings from the analyses in question.

Many project participants with prior collaboration experience. Many projects are undertaken by partners who have worked together previously. On the one hand, this can be an advantage, allowing them to build on prior work and/or existing mutual insight and trust, which may increase the likelihood of a successful collaboration. On the other hand, this can limit originality and innovation in the projects supported. It is a challenge for policy instruments to ensure that the right partners are involved in projects and that funded projects have sufficient novelty.

Few SME participants. A number of the evaluations and analyses undertaken point to the lack of small and medium sized enterprises (SMEs) among the group of participants in funded projects. Some analyses suggested the funding models for private participants as part of the explanation for this, while others identify the greater resource constraints and shorter time horizons that smaller firms generally operate under as key factors.

Box 2. List of evaluations and analyses surveyed in connection with this review

Please note that this is not an exhaustive list. Emphasis in the selection process was placed on evaluation and analyses of public instruments focused on collaboration between public research organizations and R&D-intensive firms.

2005. Videnskabsministeriet. Evaluering af centerkontrakt–/innovationskonsortiumordningen.

2008. Det Strategiske Forskningsråd. Effektmåling af strategisk forskning.

2008. Forsknings- og Innovationsstyrelsen. Effektmåling af forsknings- og innovationssamarbejder - fokus på innovationskonsortier.

2009. Det Strategiske Forskningsråd. Tværfaglighed i strategisk forskning.

2009. Evaluering af Forskningsrådssystemet.

2009. Forsknings- og Innovationsstyrelsen. Analyse af forsknings- og udviklingssamarbejde mellem virksomheder og videninstitutioner.

2010. Forsknings- og Innovationsstyrelsen. Evaluering af virkemidler, der omfatter forskningssamarbejde mellem offentlige forskningsinstitutioner og private virksomheder.

2010. Forsknings- og Innovationsstyrelsen. Effektmåling af innovationskonsortier – An analysis of firm growth effects of the Danish Innovation Consortium Scheme.

2011. Styrelsen for Forskning og Innovation. Analyse af SMV-deltagelse i DSF-bevillinger og RTI's forskningskuponordning.

2012. Kaiser, U., Kuhn, J.M. Long-run effects of public-private research joint ventures: The case of the Danish Innovation Consortia sup-port scheme. Research Policy 41, 913-927.

2012. Peer Review of the Danish Research and Innovation System: Strengthening Innovation Performance. Expert Group Report prepared for the European Research Area Committee (ERAC).

2014. DEA & DI. Fra forskning til innovation – Om virksomheders brug af erhvervsrettede forsknings- og innovationsordninger.

2014. Styrelsen for Forskning og Innovation. Erfaringsopsamling fra Pilotpartnerskaber om Innovation.

2014. Styrelsen for Forskning og Innovation. Sammenhæng for vækst og innovation En databaseret kortlægning af sammenhænge i udbud og efterspørgsel i det danske innovations- og erhvervsfremmesystem

2016. Chai, S., Shih, W. Bridging science and technology through academic–industry partnerships. Research Policy 45, 148-158. (based on data from the Danish National Advanced Technology Foundation)

Lack of active firm involvement. Several analyses identified challenges in ensuring that private participants are sufficiently involved in funded projects. Political ambitions for many of the instruments to promote collaborative research and innovation projects require that firms play a significant and constructive role, though the nature and extent of that role may differ widely depending on the project and the instrument in question. However, several evaluations and analyses lament the number of university-initiated projects versus industry-initiated projects, the fact that many firms are often brought into the consortium of applications "in the eleventh hour" and therefore do not have sufficient possibility to influence the project's focus or their role, or the fact that firms' engagement may fall dramatically during the course of the project, for a number of reasons. These findings have generally led to recommendations to involve firms earlier on in the project formulation and application process, and to place greater emphasis on the role played by private participants throughout the course of the project.

"Box ticking". Several evaluations and analyses pointed to the unfortunate tendency of funding bodies' requirements or even more or less explicit requirements of projects to lead to "box ticking" whereby applications try to fulfill as many potential evaluation criteria as possible in a bid to obtain funding. This may lead to projects, which are not designed optimally with regards to achieving a successful collaboration. One of the main complaints revolve around "arranged marriages" where certain types of participants are included in a project without being necessary or perhaps even making a valuable contribution to the project; this can increase coordination costs, lead to ineffective collaboration and dilute other participants' motivation to commit to the joint project.

IPR. Several analyses point to difficulties related to negotiations over the distribution of intellectual property rights in collaborations and in dealing, in particular, with the university technology transfer offices (TTOs). However, many of the analyses that point to these issues are older; as will be described in chapter 6 of this report, other studies document substantial positive developments in both negotiations and the efforts of the university TTOs in recent years. This may indicate that some of these challenges have lessened in magnitude or, at least, taken on a different character.

More coordination and clearer division of labor between funding bodies. A number of evaluations also call for clearer, more transparent division of labor between funding bodies and instruments, better coordination of calls, and even in some cases harmonization of application deadlines and procedures. Firms have called for simpler, smoother application procedures and administration.

For instance, a 2009 evaluation of the funding system argued that the funding bodies at the time had greater incentive to focus on their own area of operation than on ensuring a smooth and efficient overall system. A 2012 international peer review of the Danish research and innovation system suggested gathering and reorganizing funding bodies under one research council and one agency focused on innovation and applied research. However, these issues have at least in part been addressed by the establishment of the Innovation Fund Denmark and the simultaneous closure of the Council for Strategic Research, the Danish Advanced Technology Foundation, and the Council for Technology and Innovation.

5. BARRIERS TO EFFECTIVE COLLABORATION

R&D COLLABORATION OFTEN FAILS

Several studies have pointed out that firms' collaboration on research, development and innovation often results in failure, for example because of collaboration difficulties or scientific or technological obstacles encountered during the course of the venture (Brouthers et al. 1997; Kale et al. 2002; Kogut 1989; Lhuillery & Pfister 2009; Reuer & Zollo 2005). Failure is a likely outcome of R&D collaborations with various types of partners, including public research organizations but also e.g. competitors, customers and suppliers (Lhuillery & Pfister 2009). For example, studies have reported unsuccessful collaboration rates between 30 and 50 pct. (Belderbos et al. 2015)

R&D collaborations are often terminated, which in and of itself is not necessarily a problem. A joint project may for example be terminated because partners' objectives have been met earlier than expected or because R&D targets or approaches have changed, either as a result of e.g. new opportunities or learning (Reuer & Zollo 2005).

If, however, termination of a collaboration is the outcome of poor design or management, then it constitutes an ineffective use of private and public resources and is problematic. For example, partners' contrasting objectives may lead to frequent changes of direction in R&D activities and even termination before completion (Lacetera 2009). Other typical reasons for failure are the selection of unsuitable partners (Beamish & Inkpen 1995), improper governance structure (Sampson 2004) or poor day-to-day communication and management of the collaboration (Kelly et al. 2002)

In this chapter, we examine prior studies on typical barriers to successful collaboration between public research organizations and firms, and on factors that can help increase the likelihood of a successful outcome.

WHAT ARE THE MAIN BARRIERS TO EFFECTIVE COLLABORATION?

In spite of the substantial focus on university-industry collaboration, relatively few studies have systematically investigated the barriers to such collaboration. An exception is the study by Bruneel et al. (2010), which distinguished between two main types of obstacles in university-industry collaboration: orientation-related and transaction-related barriers.

Orientation-related barriers stem from the fact that firms and academic researchers are intrinsically different in their norms and behavior (Bruneel et al. 2010). For example, firms often have to produce results in the short-term, while academics can work under a much longer timeframe. The two parties also have different ways of dealing with their research results: firms generally seek to protect their R&D investments by patenting valuable results or keeping them secret, while academics have incentive to publish their findings. University researchers need to establish priority, i.e. be the first to publish key new knowledge, while firms need to turn a profit; this can be a source of conflicts. These differences are described in greater detail by, among others, Dasgupta & David (1994).

Orientation-related barriers are however likely to be reduced alongside the increasing degree of collaboration that takes place between academia and industry, as increased collaboration is likely to both bring about and be supported by gradual changes in the norms and behaviors of academics. For example, Colyvas & Powell (2006) used the correspondence of the Stanford Office of Technology Licensing (OTL) to show

how scientific entrepreneurship became more legitimate, related activities became taken-for-granted, and the overall process institutionalized. The authors also showed that the increased "taken-for-grantedness" and legitimacy of scientific entrepreneurship play an important role in permitting the expansion of the organizational reach of the OTL.

Colyvas & Powell (2007) presented a detailed study of the origins, spread and acceptance of academic entrepreneurship in the biomedical field at Stanford 1970-2000. They described academic entrepreneurship (p. 221) as

> ***… an integration of novel roles and resources into existing organizational contexts, triggering the creation of new models of what a researcher should be doing.***

Owen-Smith (2003) described how increased patenting and industry engagement in US universities has led to a substantial change in the rules that govern competition between universities, where commercial and academic standards for success have been integrated into a "hybrid regime" where achievement in one is contingent upon success in the other.

Returning to the study by Bruneel et al. (2010), the second main group of obstacles to effective collaboration was *transaction-related barriers.* These include conflicts over the ownership of intellectual property (usually patents) developed during the course of the collaboration and conflicts over university administration and bureaucracy, which firms often cite as cumbersome. Universities' growing emphasis on patents and possibilities of exploiting their patents for financial gain (see chapter 6) appears to have contributed to sources of conflict between collaborating firms and universities (Florida 1999; Shane & Somaya 2007; Bruneel et al. 2010), particularly when universities hold unrealistic expectations about the commercial value of their research (Clarysse et al. 2007).

There is even evidence suggesting that increased university patenting activity in Denmark may have deterred pharmaceutical firms from collaborating with Danish universities (Valentin & Jensen 2007). More precisely, the authors showed that the Act on Inventions at Public Research Institutions was followed by a significant decrease in the number of Danish academic inventors involved in patents owned by Danish biotechnology firms, and a corresponding increase in the firms' collaboration with academic researchers in Sweden, where the so-called "professor's privilege" remains.

Bruneel et al. (2010) found that transaction-related barriers are more difficult to mitigate than orientation-related barriers, for example in relation to negotiations over IP. Transaction-related barriers, however, are sensitive to actions taken by policymakers and university managers, insofar as these may increase or decrease the level of bureaucracy and administrative burdens associated with cooperating with a university.

Another perspective on why university-industry collaborations fail, or at least fall short of expectations, focuses on the *management* of such collaborations. For example, Perkmann & Salter (2012) argued that firms often manage their collaborations with academia on an ad hoc basis, driven by individuals rather than a coherent, corporate strategy, and often on a far less professional basis than they manage relationships to other firms, e.g. customers and suppliers. We return to the importance of good collaboration management later in this chapter.

Finally, it is important to stress that barriers to university-industry collaboration differ across countries and even universities. For instance, based on survey conducted in 33 European countries, Davey et al. (2015) found significant differences in the barriers and drivers that effect academic entrepreneurship in various parts of Europe.

KEY BARRIERS ACCORDING TO RESEARCHERS IN DENMARK

In the following two sections, we focus on available insight into the barriers to collaboration identified by academic researchers and firms in Denmark. As mentioned in chapter 2, DEA (2014a) undertook a survey of Danish university researchers' participation in commercialization activities and their collaboration with non-academic actors in both the private and public sectors. Among other things, the survey asked respondents what they perceived to be key barriers to engaging in collaboration and commercialization activities. Answers from respondents with recent non-academic collaboration experience were analyzed separately from responses from researchers who had not participated in any interaction with non-academic actors within the three years leading up to the survey period.

Three factors were identified as “key barriers” by respondents with collaboration experience (see figure 7): lack of prioritization/ reward from university management,[12] conflicting timeframes in non-academic and academic organizations (e.g. short vs. long- term focus), and conflicting goals (e.g. making a profit vs. publishing findings). Each of these three barriers was identified as a “key barrier” by approximately 20 pct. of respondents with collaboration experience.

Respondents with no recent collaboration experience identified other deterrents to collaboration (cf. figure 8): difficulties in finding qualified academic partners, conflicting goals, and the perception that their research is not sufficiently relevant for non-academic organizations. These findings suggest that efforts to stimulate these researchers to engage with industry should focus, at least in part, on helping them build networks with potential collaborators.

[12] This is in line with findings from a survey of perceived obstacles to patenting by Italian researchers (Baldini 2009).

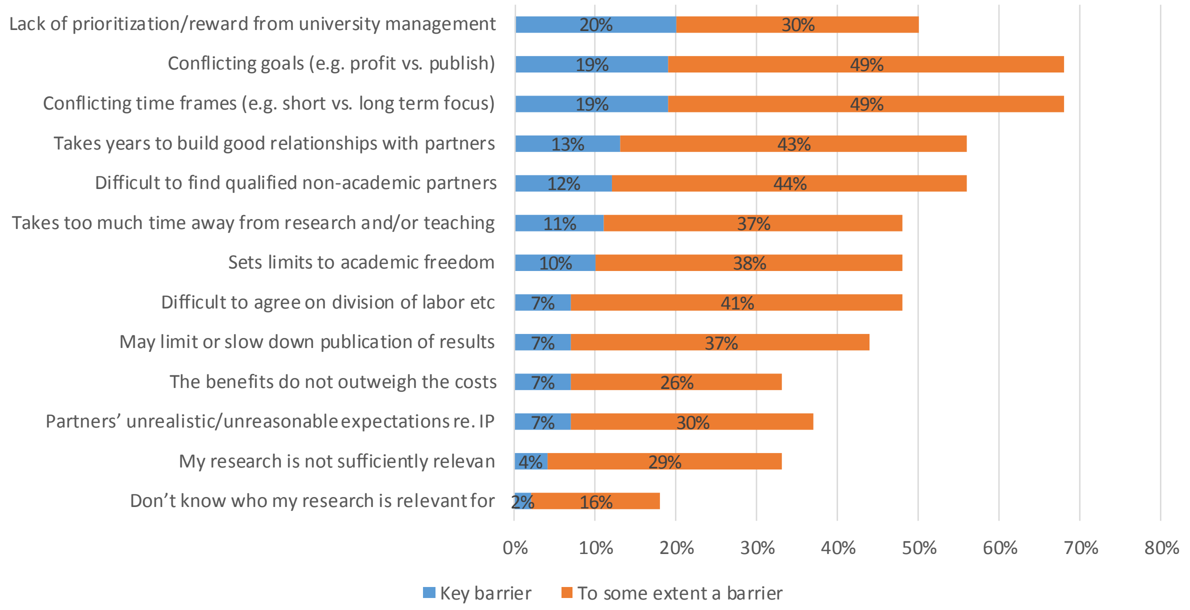
WHAT FACTORS CAN INCREASE THE CHANCE OF SUCCESS?

As previously noted, many R&D collaborations fall short of expectations or fail entirely. Nonetheless, most of the literature on university-industry collaboration assumes that such collaboration is beneficial to the parties involved (Giuliani & Arza 2009). In this section, we examine factors that may increase the likelihood of success and value creation in such collaborations.

Prior collaboration experience. A key factor highlighted in several studies is prior experience in collaborating with public research organizations (e.g. Mora-Valentin et al. 2004; Lhuillery & Pfister 2009; Petruzelli 2011), especially partner-specific experience (Reuer & Zollo 2005). Bruneel et al. (2010) found that prior collaboration experience (particularly between the collaborating parties) can service to lower the aforementioned orientation-related barriers, that is, difficulties that stem from differences in norms and behavior in academia and industry. Presumably, collaboration experience reduces such barriers as university researchers gain greater insight into industry and vice versa, and as collaborators learn how to work around differences in e.g. objectives or work habits.

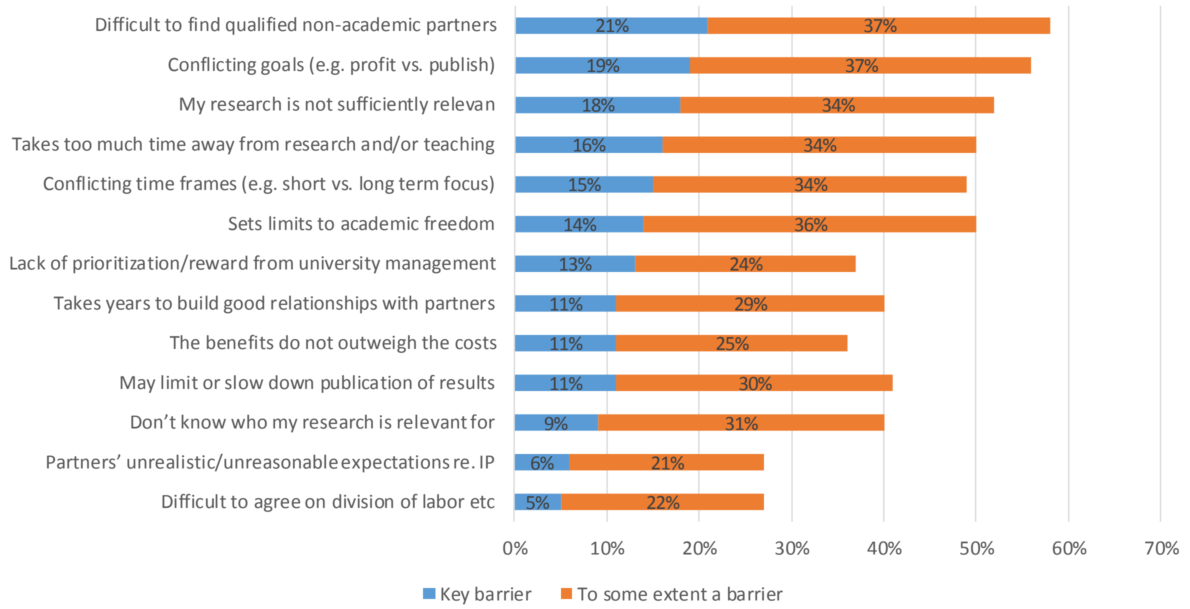
Employing multiple mechanisms for collaboration. Bruneel et al. (2010) found that engaging in a broad variety of mechanisms for interaction (e.g. joint research, licensing, consulting, contract research, collaboration on training etc.) lowers orientation-related barriers; however, this can simultaneously increase transaction-related barriers, i.e. barriers related to bureaucracy and administration, as different mechanisms and instances of collaboration are often governed by separate contractual relationships.

Figure 7. Key barriers to engaging in commercial activities and with non-academic actors, according to academic researchers with recent collaboration experience (2014 data)



Source: DEA (2014a). N.B.: Respondents who answered "never" or "don't know / not relevant" have been left out of the figure but are included in the number of observations. N(prioritization/reward) = 2,337; N(timeframes) = 2,336; N(goals) = 2,339; N(takes years) = 2,327; N(find partners) = 2,338; N(too much time) = 2,320; N(academic freedom) = 2,334; N(IP) = 2,327; N(benefits/costs) = 2,330; N(limit/slow) = 2,326; N(division of labor) = 2,332; N(not relevant) = 2,344; N(who is it relevant for) = 2,344.

Figure 8. Key barriers to engaging in commercial activities and with non-academic actors, according to academic researchers *without* recent collaboration experience (2014 data)



Source: DEA (2014a). N.B.: N(prioritization/reward) = 784; N(timeframes) = 784; N(goals) = 787; N(takes years) = 781; N(find partners) = 786; N(too much time) = 780; N(academic freedom) = 780; N(IP) = 778; N(benefits/costs) = 779; N(limit/slow) = 778; N(division of labor) = 784; N(not relevant) = 791; N(who is it relevant for) = 785.

Trust. The study by Bruneel et al. (2010) also showed that trust among collaborators reduces both orientation-related and transaction-related barriers. Trust is always an important factor in R&D collaboration, notably in ensuring that partners are willing to share valuable information and knowledge, thus allowing for for the exchange of tacit knowledge (Kogut & Zander 1992) and a successful collaboration (Ring & Van de ven 1992; Inkpen & Tsang 2005). Scholars have argued that trust may be particularly in collaborations between university and industry, because of the often highly tacit nature of the knowledge being exchanged between the parties (Santoro & Saparito 2003).

According to Bruneel et al. (2010, p. 861), the importance of trust in mitigating barriers to collaboration calls for

> ***… a focus on face-to-face contacts between industry and academia, initiated through personal referrals and sustained by repeated interactions, involving a wide range of interaction channels and overlapping personal and professional relationships.***

R&D intensity and commitment. Lhuillery & Pfister (2009) examined collaboration failures among French firms using data from the French Community Innovation Survey (CIS). They found that firms were less likely to encounter cooperation failures if, among other things, they were larger firms, operated in industries where firms are able to better appropriate their research results (through e.g. patents or secrecy), had higher R&D intensity, and if they invested in fundamental research.

The size and research capacity of firms are likely to affect their use of different channels for university-industry collaboration (Bekkers & Freitas 2008). For example, public science has been shown to have a greater impact on R&D in large firms and start-ups than in other types of firms (Cohen et al. 2002).

Generally speaking, firms that invest heavily in R&D are more likely to possess "absorptive capacity" (Cohen & Levinthal 1989, 1990), defined by Cohen & Levinthal (1990, p. 128) as

> ***… a firm's ability to recognize the value of new information, assimilate it, and apply it to commercial ends.***

Absorptive capacity is crucial to firms' ability to identify relevant partners and to engage in and benefit from collaboration with public science (Ham & Mowery 1998; Fontana et al. 2006). As Fabrizio (2009) pointed out, sources of absorptive capacity can for example be investments in in-house research (Cohen & Levinthal 1989; Rosenberg 1990), the routines of the firm (Zahra & George 2002), employee skills (Vinding 2006) and similarity between collaborating parties' knowledge sets (e.g. Dyer & Singh 1998; Lane & Lubatkin 1998). However, studies have also shown that while some degree of similarity in competencies and capabilities is important for collaboration, too much similarity can have a negative impact on the results of the collaboration, as some level of diversity and complementarity is necessary for productive collaboration (see e.g. Petruzelli 2011). The concept of absorptive capacity is important to understanding why firms benefit to different degrees – and sometimes not at all – from collaboration with public science (Fabrizio 2009).

Based on data from a survey of UK firms that collaborated with universities, Bishop et al. (2011) found that firms are more likely to gain from their collaboration with universities when they show a continued commitment to engage in R&D, and possibly also when they have a higher R&D intensity, though results were less conclusive on this point.

The same study showed that collaborating with top-ranked university partners has a positive and significant impact on outcomes such as the generation of patents, training of company staff, and for downstream activities. Other benefits of collaboration, e.g. gaining access to information for new ideas, were obtained regardless of whether the university partners were top-ranked or not. The authors argue, with reference to prior research, that both top-tier and lower-tier universities may play important roles in collaborating with firms. For example, lower-ranked universities produce many of the findings that firms consider to be important for product and process development and may have staff who are more willing to focus on the information needs and immediate problems of firms (Mansfield & Lee 1996).

Proximity. Bishop et al. (2011) also found that firms were more likely to benefit from collaboration when there is geographical proximity between the firm and the university.[13] Their data suggested that proximity to university collaborators is particularly important for problem-solving, presumably because of the importance of tacit knowledge exchange for solving complex problems.

Geographical proximity can reduce firms' search costs (Feldman 1999) and is particularly important for the transfer of tacit knowledge (Maskell & Malmberg 1999). Proximity also supports the building of trust and stronger, more lasting collaborations (Bennet et al. 2000; Love & Roper 2001; Abramovsky & Simpson 2011).

Interestingly, Hewitt-Dundas (2013) showed, using data from the UK business innovation survey, that there are significant differences – in business size, sales profile, location, absorptive capacity and innovation activity – between firms that cooperate with local universities and those that cooperate with non-local universities. The author also found that businesses that are located close to a research excellent university tend to cooperate mostly on a local level. Hewitt-Dundas (2013), amongst others, has also emphasized the importance of geographical proximity for the transfer of tacit knowledge from universities On a related note, Drejer & Vinding (2007) conclude that businesses with lower absorptive capacity are more likely to network locally and those with higher absorptive capacity are more likely to be connected to global networks. De Fuentes & Dutrénit (2016) also found (using Mexican data) that firms with higher levels of absorptive capacities tend to interact more independently of their location; they also found that interaction with non-local universities tended to revolve around the transfer of *codified* knowledge, while collaboration with local universities included more *tacit* forms of knowledge.

Other scholars, e.g. Arundel & Geuna (2004) and Mora-Valentin et al. (2004) have also emphasized the importance of proximity for allowing firms to draw effectively on insight from public research organizations. This is because proximity allows parties to meet more frequently, have more effective communication, build stronger ties and thereby build trust (McDonald & Gieser 1987; Katz 1994). However, as Mora-Valentin et al. (2004) point out, proximity is not an objective concept but rather depends on e.g. the available transportation infrastructure.

Better management. As previously mentioned, Perkmann & Salter (2012) have suggested that many firms take an ad hoc approach to managing their collaborative relationships with academia. On a similar note, Dodgson (1992) underlined the role of effective management in benefiting from the collaborations that firms enter into; he argued that R&D collaborations are in high need of management, among other

[13] Similar results have been obtained by e.g. Anselin et al. 1997, 2000; Beise & Stahl 1999; Autant-Bernard 2001; Acs et al. 2002

things to build effective communications paths between the collaborating parties, and to ensure the success of the technical content of the collaboration.

Perkmann & Salter (2012) argued that more effective, successful collaborations can be achieved by selecting the right model for collaboration, based on careful consideration of the aims, time horizon and degree of openness involved in the specific collaboration. They propose four alternative modes of collaboration:

- *The idea lab*, where secrecy concerns are put aside in order to generate new options,
- *The grand challenge* aimed at creating valuable new knowledge, which is subsequently to be placed in the public domain,
- *The extended workbench,* which involves quick and focused collaboration on proprietary problems and solutions, and
- *Deep exploration,* that is, rich and long-lasting collaborations around issues of joint interest, where the firm usually has rights of first refusal to inventions that may emerge.

Finally, some studies have emphasized the importance of partners' commitment to the joint venture (e.g. Ham & Mowery 1998; Mora-Valentin et al. 2004). This is confirmed by the aforementioned non-academic study of Danish firms' use of public research and innovation programs (DEA & DI 2014), which pointed to a potential for firms to step up their strategic management of the collaborations that they enter into with public research organizations. For example, the study stressed the importance of ensuring that collaborations have support from top management and firmly anchored with senior staff in the company. The study also proposed that active participation by a company in a collaborative venture ought to be motivated by a clear strategy for what the company expects to achieve and how it expects to further develop and apply the results of the project. Likewise, it is important that company participants allocate resources, throughout and after the project, to build up in-house absorptive capacity, provide inputs to the direction of the project, and to determine how to continue work once the project has been completed. This may for example require hiring or allocating experienced staff to the project, both during and subsequent to the collaboration, and setting clear goals for the company's efforts to further work with project results.

PART III. "STATE OF THE ART" INSIGHT INTO KEY MECHANISMS FOR UNIVERSITY-INDUSTRY INTERACTION

6. IP-BASED TECHNOLOGY TRANSFER

WHAT IS TECHNOLOGY TRANSFER?

In their search for a higher payoff from public investments in science, policymakers have in recent decades focused extensively on encouraging technology transfer as a means of boosting the commercial exploitation of university research.

Technology transfer refers to a direct transfer of research-derived knowledge, techniques, instruments and/or technology by a public research organization to a firm with a view to their commercial exploitation. Technically, the public research organization will sell or license the intellectual property rights to the receiving firm; the most common form of IPR are patents. This is often followed by some degree of post-deal management, where the university retains contact to licensors in order to ensure that the technology is actually in use.

The intellectual property may be transferred to an established firm or to newly founded spinouts or other startup firms. In chapter 7, we take a closer look at academic spinouts firms, whereas this chapter is concerned with technology transfer activities in general.

It can be difficult and even artificial to distinguish between "knowledge transfer" and "technology transfer." As technological advancements build on (often tacit) research knowledge, technology and knowledge transfer tend to go hand in hand (Sahal 1981; Bozeman 2000).

Technology transfer activities at public research organizations are often managed by a central technology transfer office (TTO), knowledge transfer office (KTO) or some other, similar unit. They may, however, also be managed wholly or partly by dedicated personnel in specific departments, research groups or other decentralized organizational units.[14]

However, not all research developed by a university is patented by a university. Based on data from the PatVal database on European inventors in six European countries, Crespi et al. (2007) showed that university-owned patents account for only 15 pct. of patents with at least one academic inventor. Similar findings have been published by Geuna & Nesta (2003, 2006) and Lissoni et al. (2008); the latter argued that the share of patents from European public research organizations which are directly assigned to corporations is estimated to be in the 60 to 80 pct. range. By comparison, US data indicate that 26 pct. of university inventions are assigned solely to firms (Thursby et al. 2009).

Overall, these findings suggest that statistics on patents owned by European universities paint a misleading picture of universities' contribution to innovation, as indicated by patenting (Geuna & Muscio 2009).

What determines who patents with university inventors get assigned to? A study based on German data (Czarnitzki et al. 2012) indicated that patents are more likely to be assigned to firms when they are less basic in nature and/or when

[14] For the sake of simplicity, in this report, we refer to all possible organizational set-ups for institutional support of knowledge and technology transfer as, collectively, TTOs.

they have a high blocking potential in technology markets, presumably because they have a higher probability of generating returns in the short term. In corollary, the inventions that are patented by public research organizations appear more basic and complex in nature (Czarnitzki et al. 2012). In a study of patenting activity in a French university, Azagra-Caro et al. (2006) found that the type of external funding obtained influenced the type of patents taken out: public funding was associated with university-owned patents, while private funding was associated with non-university owned patents.

Regardless who patents are assigned to, the successful transfer of university inventions and knowledge is not an easy task. As stated by Geuna & Muscio (2009, p. 102):

> ***In the last 30 years US and European countries have attempted to develop ''the right'' infrastructural/organizational support to ease knowledge exchange between universities and companies. More than 30 years of mostly failure (but some success) in terms of policies designed to support [knowledge exchange], have highlighted the difficulties inherent in the development of a successful organizational set up for the transfer of knowledge (and technology) from universities to businesses and society.***

BACKGROUND FOR THE GROWING FOCUS ON UNIVERSITY PATENTING

In chapter 1, we described the growing focus among policymakers on strengthening the interplay between public science and private innovation in general, and on efforts to patent and transfer university research in particular. In this section, we briefly review the story behind the global growth in university patenting, based on prior reviews by the author (Larsen 2007, 2011).

Policymakers and legislators are increasingly encouraging or, in some countries, requiring universities to patent research results and to pursue their commercialization through for instance licensing deals or the establishment of academic spinout companies.

The past few decades have seen a dramatic increase in the number of patents taken out by academic scientists and organizations in both the US (Henderson et al. 1998) and Europe (Lissoni et al. 2008). In the US, the Bayh-Dole Act of 1980 played an important role in expanding IPR protection for publicly funded research by placing the responsibility for patenting and subsequent commercialization activities with universities (Mowery, 1998; Mowery et al., 2001). It is interesting to note that the Act was passed in order to simplify and streamline procedures for the appropriation and licensing of inventions developed through federally funded research, and not to encourage the development of new sources of income for universities per se (Mowery et al. 2001; Verspagen 2006).

More recently, similar changes to the legislation governing the protection of intellectual property created from publicly funded research have been made in a number of European countries (see Geuna & Rossi 2011 for a review).

Current policy initiatives toward greater enterprise in academia have however been criticized for being largely based on anecdotal evidence of successful licensing and spin-off activities from US universities such as Columbia University, Stanford University and Massachusetts Institute of Technology, in spite of the lack of solid, empirical support for the argument that patenting stimulates the transfer of university technology to industry, and in spite of the ambiguous nature of current empirical evidence on the long-term implications of academic enterprise (Geuna & Nesta 2006; Verspagen 2006).

Concerns have also been expressed that policy justifications are based to a large extent on unrealistic expectations regarding the income streams that may be generated from the commercialization of academic research (Feller 1990; Nelson 2001, 2006); we return to these concerns later in this chapter. Numerous studies have called for caution in overestimating the economic value of university patenting and regulations like the Bayh-Dole Act. Empirical research suggests that the Act was but one of several key factors behind the rise in academic patenting,[15] alongside in particular the increasing ease with which some forms of fundamental research, notably within the life sciences, but also in electronics and software, began lending themselves to patenting (Mowery et al. 2001).

Studies have moreover indicated that increases in patenting activity in American universities were associated with a decrease in the quality and value of university-held patents (Henderson et al. 1998; Mowery & Ziedonis 2002).[16] Other studies have shown that the Bayh-Dole Act prompted universities to increase patenting in fields in which licensing is an effective mechanism for acquiring new technical knowledge (Shane 2004b).

Regardless, numerous studies have emphasized the role of legislation on university patenting and related policy changes in stimulating and facilitating the transfer of university technology to industry and the development of spin-off companies based on academic research findings (e.g. Etzkowitz & Leydesdorff 2000; Di Gregorio & Shane 2003; Shane 2004a; Hellman 2005; O'Shea et al. 2005).

PATENTS ARE JUST "THE TIP OF THE ICEBERG"

Policymakers have focused heavily on technology transfer in recent decades, partly because of its potential to deliver concrete and relatively easily measurable examples of commercial exploitation of university research (D'Este & Perkmann 2011), and partly because of expectations that it will also contribute to universities' overall income.

The emphasis that technology transfer has received, however, appears misplaced. As described in chapter 2, IP-based transfer of university research and technology account for just the "tip of the iceberg" when looking at universities' overall interaction with industry and society at large (Salter 2002; Salter & Perkmann 2012). It is but one of many channels for public research organizations' knowledge exchanges with industry, and both in volume and importance a lesser one at that (Meyer-Krahmer & Schmoch 1998; Agrawal & Henderson 2002; D'Este and Patel 2007; Perkmann and Walsh 2007).

DO UNIVERSITIES MAKE MONEY FROM THEIR PATENTS?

Technology transfer is not only a hot topic in policy circles because of its contribution to the commercial application of public research results; it also generates revenue to the public research organizations that owns the rights to the technology being transferred. Such revenue is particularly interesting for universities and other public research organizations in view of the increasing costs of scientific research, coupled in several European countries with decreasing

[15] Some scholars have questioned how great an impact legislation on university patenting really has on patenting activity, arguing that such activity was on the rise before legislative measures were passed in the US as well as in several European countries (e.g. Mowery et al. 2001; Colyvas et al. 2002; Kenney & Patton 2009; Geuna & Rossi 2011; Kochenkova et al. 2015).

[16] Sampat et al. (2003) questioned, however, the validity of the findings by Henderson et al. (1998), arguing that these findings reflected changes in the intertemporal distribution of citations to university patents, rather than a significant change in the total number of citations these patents eventually receive.

government funding for academic research (Geuna 1999, 2001).

Several studies show, however, that most universities do not turn a profit from their patenting activities (see e.g. Thursby et al. 2001; Geuna & Nesta 2006). For example, Mowery et al. (2001) argued that few universities make money from their patents, and that a small number of patents account for a disproportionately large amount of the revenues from licensing in three universities leading the way in academic patenting, namely the University of California, Stanford University, and Columbia University.

The fact that most revenues from university patenting and licensing stem from a small fraction of the total number of patents and deals is confirmed in a recent international study (OECD 2013). Moreover, Thursby & Thursby (2007) found that just 0.48 percent of all active licenses generated licensing income of $1 million or more in the US.

On a related noter, Scherer & Harhoff (2000) calculated that the top ten percent of all Harvard patents provided 84 percent of the gross economic value of Harvard's patent portfolio.

Similarly, Stanford University has made most of its licensing income from a small number of key patents, including the patent behind recombinant DNA technology, which essentially enabled the development of the biotech sector, and the algorithm behind Google's search engine (Stanford Office of Technology Licensing 2010). In fact, less than 1 pct. of the inventions disclosed by researchers at Stanford have generated more than a million US dollars in total royalties (Merrill & Mazza 2010).
A recent study from the Brookings Institution has confirmed and extended the findings from the aforementioned study by Mowery et al. (2001): Valdivia (2013) concludes that most American universities lose rather than make money off their patents. He found that the top 5 pct. earners, as indicated by licensing income, account for 50 pct. of the total licensing income in the US university system. The top 10 pct. earners account for 70 pct. or almost three quarters of all university licensing income in the US.

Valdivia (2013) also found that the top earners are a relatively exclusive club of universities, as there is relatively little change from year to year in who the top earners are.[17] This can presumably be explained, at least in part, by the aforementioned fact that most licensing income can be traced back to a small handful of valuable patents that generate a steady stream of income over their lifetime.

The study from Brookings Institution moreover showed a strong relationship between universities' licensing income and public funding. This lead Valdivia (2014) to conclude that

> ***If high licensing revenues are a lottery, then it is one in which only universities with the highest federal funding can participate.***

According to the author, this indicates that a prerequisite for successful patenting is having a critical mass of funding needed to build the research capacity needed to produce research which is both novel and interesting to industry.

Last but not least, Valdivia (2013) emphasized that patenting generates substantial costs for the universities who engage in it: even among the 20 top-earning universities in the US, he could find only five who made a profit. The other top earners do not make enough income to

[17] This finding is supported by Heisey & Adelman (2011) who found that the early initiation of technology transfer programs and staff size are associated with higher expected licensing revenues, although early entry and staff size appear to be substitutes. Moreover, the authors found that one-year lagged licensing revenue had strong predictive power for current licensing revenue.

cover the costs of their technology transfer activities.

Similar circumstances have been documented in Europe (see e.g. OECD 2013), where 10 pct. of universities account for about 85 pct. of all income from the licensing of university patents (European Commission 2012; OECD 2013).

Concerns have also been expressed regarding the impact of revenue-maximizing models for TTOs on the dissemination of university knowledge and technology. For instance, Link et al. (2007) argued that rewarding TTOs based on the revenues they generate rather than on the number of inventions that are transferred to industry often inhibits the dissemination of innovations. Siegel et al. (2004) argued that an excessive focus on patents as a mechanism for transferring innovations to industry represents an oversimplification of the knowledge exchange process, which moreover contributes to an underestimation of other important means of knowledge transfer from universities to industry.

Nonetheless, the dream lives on for many. As argued by Nelson (2006, p. 914),

> ***Although the notion that universities can get rich from licensing revenues is, except for a few cases, misguided, dreams die hard. Universities will not give up the right to earn as much as they can from their patenting unless public policy pushed them hard in that direction.***

In an effort to put licensing incomes into perspective, D'Este & Perkmann (2011, p. 331) point out that

> ***… the intention of policy-makers is not necessarily to maximize universities' income, but rather to make technology available to firms and society at large.***

On a similar note, Geuna & Nesta (2006, p. 794) criticized the heavy emphasis placed by policy-makers on university patenting as a mechanism for technology transfer:

> ***… 'benefits' [of IPR-based technology transfer] are presented without any supporting statistical empirical evidence and can only be regarded as a mixture of suppositions and expectations.***

Geuna & Nesta (ibid.) further argued that the putative advantages of patenting as a means of commercialization have been presented

> ***… with no spelling out of the possible costs or risks involved. To say the least, this conveys a rather onesidedly favourable picture; it is policy advocacy freed not only from the requirement of evidence-based policy, but also from comprehensive analytical assessment of the plausible range of consequences.***

THE ROLE OF THE TTO

Before the establishment of TTOs, knowledge and technology transfer activities occurred as an element in personal relationships between academic researchers and industry and government; researchers acted on a personal basis as advisers, consultants and problem solvers, in return through endowments and gifts rather than specific contracts, and usually without direct involvement of the university (Geuna & Muscio 2009).

Today, universities' technology transfer offices (TTOs) help researchers to disseminate their findings, manage the university's intellectual property portfolio, broker ties to seed investors and venture capitalists, and support researchers in establishing spinout firms (Berbegal-Mirabent et al. 2007; Brescia et al. 2016).
As such, they play a key role in determining the success of a university's patenting and licensing

activities (Anderson et al. 2007). However, several prior studies have shown that many TTO's are inefficient and/or lacking in crucial competences (Anderson et al. 2007), for example due to culture clashes with industry or with academic research staff, bureaucracy and a lack of pragmatism and flexibility, and poor management of the TTOs (Siegel et al. 2003c; Grimpe & Fier 2010). In addition, procedures for the realistic valuation of university owned patents and their market opportunities are in many cases poorly developed (Leitch & Harrison 2005).

In view of the difficulties experienced by most universities in breaking even on their technology transfer activities, it is often suggested that TTOs could be merged across universities. While this could create economics of scale, TTOs however also often need to maintain close relationships with the researchers that they support (Veugelers 2014), arguing in favor of more decentralized TTO operations.

TTOs have become vital but not always effective agents in knowledge and technology transfer processes (Geuna & Muscio 2009). For example, technology licensing officers in the TTO play a crucial role in deciding which inventors to license; Shane et al. (2015) showed that they tend to favor academic inventors that that ''fit'' the profile of a typical inventor-entrepreneur. The characteristics licensing officers look for are, at least in the US, male immigrants with industry experience who are easy to work with.

TTOs may actually slow down rather than accelerate the transfer process, because they seek to safeguard the interests of the researchers and the university, and to maximize financial returns to the university (Siegel et al. 2007). Also, Litan et al. (2008) argued that policies pursued by TTOs may cause them to block rather than facilitate transfer of university knowledge or technology, particularly when emphasis is placed on the financial revenues of the TTO rather than on the knowledge transferred.

In fact, several scholars argue that the linear, patent-centred approach to technology transfer in which inventions or discoveries are disclosed to the TTO, then patented and licensed is based on an oversimplification of the technology transfer process, which is rarely linear and which draws on far more mechanisms than patenting (e.g. Siegel et al. 2004; Geuna & Muscio 2009). For example, Perkmann et al. (2013) pointed out that commercialization will often be an outcome of or follow-on activity to actual collaboration between university researchers and industry, rather than a stand-alone activity. Commercialization may also be accompanied by collaboration, e.g. when spinouts work with the research labs that they originated from (Meyer 2003) or to transfer tacit knowledge to or explore new research avenues with companies that have licensed an invention.

As a result, many TTOs have expanded the range of services they offer from a narrow focus on patenting and licensing to a broader set of knowledge transfer activities (OECD 2012). TTOs also appear to have placed a lot of emphasis on increased the competencies of their staff, through training and their recruitment practices (OECD 2012). There are several different models for organizing TTO activities, with each their set of advantages and disadvantages (Schoen et al. 2014). TTOs are continuously evolving in their search for more effective operational models (OECD 2013). In fact, OECD (2013, p 67) stated that:

> ***Anecdotal evidence suggests that a large number of TTOs have expanded their activities from administrating technology transfer (invention disclosures, filing patents) to a wide range of IP management and supporting activities (e.g. patent scouts, consulting), marketing non-patent services, administering proof-of-concept (PoC) and seed funds for entrepreneurial activities, as well as promoting an innovation culture… However, there is still much variety in the missions and models of TTOs as well as in the nature of the institution***

they serve. This is mainly due to variations in resource and infrastructure endowments among institutions, the scale and focus of research efforts, and experience in technology transfer.

Other scholars have examined specific issues that may arise in dealing with TTOs. For instance, Franza et al. (2012) investigate the problems that external collaborators experience when entering into technology transfer contracts with R&D labs. Drawing on insights from prior studies, the authors emphasize the importance of factors such as the cooperative competency of the units involved in the negotiations, common values between partners, and allowing for flexibility in the contractual relationship. They find that overspecification and too much contract detail can have negative implications for the image of the lab, for employee morale, and of the efficiency and effectiveness of management of the lab.

On a related note, Bercovitz & Tyler (2014) argued that as scientists gain experience in contracting with external partners, they focus increasingly on establishing and supporting relationships based on technical competence, behavioral experience, and operational routines, causing the enforcement terms of subsequent contracts to become less detailed. However, administrators – because of the activities they work on and their responsibility to mitigate opportunism and enforce good contracts – primarily build up experience in governing (not undertaking) collaboration; as a result, their experience may lead the enforcement terms of subsequent contracts to become more detailed. This may lead to conflict.

van den Berghe & Guild (2008) argued that firms will often pursue exclusive licensing agreements with universities in the goal of protecting and maximizing the return on their investments in a university invention, while university TTOs can be reluctant to give exclusive rights as this may limit the commercial use of the invention. Based on a study of 66 technology transfer projects in the information and communications technology industry, the authors found that exclusive rights are typically granted only when the new technology has a high strategic value to the firm, thus increasing the likelihood that the firm will secure adequate investment support and management attention, thereby also increasing the probability of successful commercialization.

WHAT MATTERS FOR SUCCESSFUL TECHNOLOGY TRANSFER?

Based on interviews with scientists, administrators and university managers, Siegel et al. (2003b) pointed to the difficulties involved in bridging the cultural gap between universities and industry and recommended that universities hire people with a professional background in industry as a means of reducing cognitive and cultural distance. The authors also called for universities to show more flexibility when negotiating agreements with industry and to abandon goals of royalty maximization when this may hinder further collaboration with industry.

A study of TTOs at US universities suggests that speed of commercialization may be positively linked to performance: Markman et al. (2005a) found that the faster TTOs can commercialize patent-protected technologies, the greater their licensing revenues streams and the more ventures they spin off. They further argued that speed is likely to be a function of, among other things, TTO resources, the competency in identifying licensees and the participation of academic inventors in the licensing process. Murray (2004) argued that the importance of the participation of academic inventors is explained not just by their personal scientific and technical knowledge and their problem solving skills, but also by their social capital, i.e., the social networks that they have built up to industry during their careers.

Berbegal-Mirabent et al. (2015) pointed to the importance of TTO budget size and accumulated experience in explaining TTO success.

Okamuro & Nishimura (2013) argued, based on a study of university-industry collaboration in Japan, that university IP polices that are equitable in sharing revenue and royalty from innovative outcomes and applied flexibly according to partners' needs can contribute to more successful collaborative projects by enhancing the commitment of firms.

On a related note, recent research suggests that how researchers are funded may affect their propensity to develop valuable patents and thus, potentially, spinouts. Guerzoni et al. (2014) examined why some university patents are more valuable than other. More precisely, using data on patented cancer research, they investigated how scientists' funding sources are associated with patent originality. The authors found that university scientists who partly funded by their own university have a higher propensity to generate more original patents. By contrast, university scientists funded either by industry or other non-university organizations have a lower propensity to generate more original patents.

Finally, relatively little is known about how private firms choose which technologies to license. Thursby & Thursby (2003) examined the factors that influence firms' choices, yet this remains understudied and a valuable avenue for further research.

TECH TRANSFER IN DENMARK

Up until the year 2000, researchers at public research organizations in Denmark enjoyed the so-called "professor's privilege", allowing them to determine what to do with inventions developed as part of their research.

The *Act on inventions at public research institutions*[18] was a Bayh-Dole Act type of legislation which came into force on January 1, 2000. It gave universities, government research laboratories and public hospitals the *option* of taking over the rights to inventions developed by their staff, but also the *obligation* to actively pursue to commercial exploitation of those inventions, which they decide to take ownership of.

The aim of the Act was to promote increased commercial exploitation of publicly funded research and thereby boost society's return on investments in science. The Act was however also accompanied by widely held expectations that at least some universities would be able to reap substantial financial rewards.

For example, part of the written rationale for the Act specifically stated that public research organizations lack incentive to invest in technology transfer because they generate no income from their inventions.[19] Not only did universities gain the possibility of accessing income from the sale or licensing of their inventions; they were also assessed on their ability to make money from their patents, despite the aforementioned lessons from the US, namely that very few universities, and indeed very few inventions, account for the lion's share of licensing activity and income in the US university system. Nonetheless, the two largest Danish universities, the University of Copenhagen and the University of Aarhus, were subject to income targets on their technology transfer activities in their development contracts until 2012.

The Act on university inventions led initially to the establishment of legal offices and, later, to

[18] In Danish: "Lov om opfindelser ved offentlige forskningsinstitutioner" (Forskerpatentloven).

[19] Source: Skriftlig fremsættelse (18. november 1998) af Forslag til lov om opfindelser ved universiteter og sektorforskningsinstitutioner af Forskningsministeren (Jan Trøjborg).

the formation of actual TTOs in the Danish universities. A qualitative, non-academic study from DEA (2013) examined key development and learnings from technology transfer activities in Danish universities since 2000. Some of the main conclusions from this study and a recent follow-up publication (DEA 2016) are described in the following.

TTOs have shown significant improvements since 2000. Despite widespread criticisms of the TTOs from policymakers, researchers and firms alike, there has been a significant and positive development in technology transfer activities in Danish universities. Efforts have been continually adjusted based on learning, bringing TTOs from legal patent offices to offices spanning across a broad range of mechanisms for knowledge exchange. However, universities are exploring very different models for knowledge exchange, and there is still much room for improvement. Among other things, it is important to support continued efforts in universities to use TTO resources more efficiently, for instance by concentrating resources on fewer inventions with considerable market or societal potential (aiming for quality rather than quantity), and where serious potential users and investors are involved in the further development and maturation of the technology. (DEA 2013)

Technology transfer should be seen as an investment in the dissemination of research. Tech transfer is in Denmark, as in most universities abroad, finding it hard to reach break-even, and should probably be seen as an unprofitable investment in the long-term dissemination and transfer of university research. The technology transfer system was however established based on the premise that it would pay for itself via income from licensing and sale of IP. Since this is not the case, universities are today forced to fund the difference between their income and the costs of running a TTO, maintaining patents and engaging in post-deal management etc. out of their base funding, which is intended for long-term development of the university's research and teaching capacity. As such, university managers do not have sufficient incentives to invest optimally in technology transfer and knowledge exchange activities. There is a need for policymakers to discuss the consequences of seeing technology transfer as an investment rather than a source of income, including what the socially desirable level of investment of technology transfer activities and how a sustainable, long-term funding model for these activities can be designed. (DEA 2013)

The importance of patents as a means of transferring university research and technology have been overstated. As discussed in chapter 2 of this report, patenting is but only of several possible mechanisms for knowledge exchange and often not the ideal one. Moreover, it rarely stands alone, but usually emerges from or leads to some form of direct collaboration between academic researchers and industry, aimed e.g. at the transfer of tacit knowledge or at exploring new research paths. It is therefore not in the transfer of patents that real value is created but rather in the collaboration between researchers and firms. (DEA 2013)

Difficulties in university-industry contract negotiations. The Act on Inventions that came into force in 2000 has made university-industry negotiations more difficult, particularly as all collaborations must be preceded by an agreement regarding the distribution of intellectual property rights and possible future income from these that might (but usually don't accrue) from the collaboration. There are no easy solutions for increasing the efficiency of these negotiations, though several practices appear promising. These include drawing standard framework agreements between frequent collaborators, thus minimizing the need for continuous renegotiation, and ensuring that legal negotiations are handled by seasoned (not inexperienced) legal advisors in close dialogue with senior researchers and company management involved in the collaboration. (DEA 2013)

Such problems arise due to the fact that TTO staff and legal staff have strong incentives to seek to protect the university's rights and to minimize risks, thus often leading to overly detailed contracts, while the actual collaborators often have a more pragmatic interest in establishing a mutually satisfactory starting point for the collaboration and lean towards less detailed agreements as they build up collaboration experience (Bercovitz & Tyler 2014).

Disagreements over the value of university research. In addition, companies and universities often disagree on the financial value of university inventions. Essentially, Danish universities currently have strong incentives to seek to drive prices up, while firms – due to the significant risk involved and the need for substantial further R&D – have incentives to drive prices down. The situation is compounded by sustained (albeit greatly reduced) focus on universities' income from IP licensing and sale, and by unclear interpretations of universities' legal requirements to sell IP at "market prices" (given that there is, as of yet, no real market for the product, universities looking to err on the side of caution will seek the highest price possible). (DEA 2013)[20] Conflicts over the value of and income from IP are not exclusive to Denmark (see e.g. Hertzfeld et al. 2006; OECD 2013).

What's the alternative? If the aim of technology transfer is not to generate income for the university but rather to get promising inventions into the university sector, some promising models include the use of windfall clauses, option agreements, and even supporting universities in renouncing the rights to potential inventions against an upfront lump sum when entering into selected collaborations (DEA 2013). In fact, there is even an argument for making university patents freely and widely available, a practice which is gaining traction in some parts of the international academic world (DEA 2016). According to OECD (2013, p. 62), a number of universities have begun experimenting with new models for ownership of university-developed IPR:

> ***The University of Glasgow, for example, introduced in 2010 the Easy Access Programme to provide free access to university inventions on a royalty-free and fee-free basis. In March 2011, the UK Intellectual Property Office backed a proposal from the universities of Glasgow, Bristol and King's College London to develop a consortium of universities into the Easy Access Innovation Partnership. The University of New South Wales in Australia and CERN (European Organization for Nuclear Research), a major intergovernmental research facility, have also adopted versions of the Easy Access IP framework. A similar approach has been followed by Penn State University in the United States, which is no longer required to own IP arising from industry-sponsored research.***

New models for the dissemination of university patenting include open access patents, public patents and two-tiered patent strategies; these are discussed in detail by Van Overwalle (2006). Litan et al. (2008) discuss the potential of another set of alternatives to the traditional IPR licensing model, include open source collaborations, copyright, nonexclusive licensing, and a focus on developing the social networks for graduate students and faculty to commercialize all types of innovations.

Support for such efforts come from Feldman et al. (2007), who showed that non-exclusive licensing is the most suitable approach to maximize the diffusion and use of a process patent,

[20] This conflict may be compounded by the fact that university TTOs have limited bargaining power among other things because of the early-stage (and thus more immature and uncertain) nature of the types of technology universities can usually license (Jeong & Lee 2015).

and Antonelli (2008) who argued that non-exclusivity of IPR on the results of research performed under contract is necessary for the academic system to work effectively. Free and wide licensing of patents from Danish universities is probably not a realistic model, but the idea serves as a reminder that there are alternatives to the technology transfer model pursued today.

Strengthening researchers' incentives to engage with industry. DEA (2013) also argued that the benefits of technology transfer activities do not – for many researchers – outweigh the costs, or at least this is a common perception among academics. A key barrier is the perceived lack of recognition from university management and pay-off from such activities for advancement in an academic career. However, as shown in DEA (2014a) and as described in chapter 3, the majority of Danish academics who engage with industry experience benefits for both their research and teaching activities; this is in line with findings from international research on the positive relationship between engagement and entrepreneurial activities on the one hand and scientific performance on the other, as reviewed in chapter 3. These findings suggest that efforts should be made to increase awareness of the potential synergies between traditional and "third stream" missions in academia, and to support researchers in achieving these synergies. DEA (2013) also pointed to the need for other initiatives, including offering more flexible career paths and creating better opportunities for mobility between academia and industry (e.g. via part-time positions and employee exchanges). DEA (2013) also emphasized that engagement with industry should be voluntary, not mandatory,[21] and to strive to ensure that some, not necessarily all, researchers in each research unit has contact with industry, to help ensure a regular, two-way flow of knowledge between the research unit and relevant collaborators in industry.

Measure technology transfer and knowledge exchange efforts based on quality not quantity. TTOs in Danish universities today cover a wide range of functions, running the risk that resources are spread too thinly. Moreover, there are some implicit contradictions between some of these functions. One such example is the focus on patenting as a means of knowledge transfer, though patents are not always, as previously described, the optimal route. Another example is the aforementioned conflict between universities' incentives to drive prices on university IP up and their simultaneous task of ensuring smooth transfers to inventions to industry. There is therefore potential to decide and communicate which tasks and objectives TTOs should prioritize. In addition, TTOs are still measured largely on the volume of invention disclosures, granted patents, licensing deals, spinouts etc., giving them an incentive to aim for quantity rather than quality in their activities. For example, improving the quality of invention disclosures requires resources to engage with researchers before the point of disclosure, but will lead to a decrease in the number of disclosures. Likewise, universities have an incentive to pursue patents and licensing deals even if they are not the optimal route to commercialization and even if their chances of commercial success are limited. There is therefore a need to develop the indicators used to assess universities' technology transfer activities and their use by policymakers to incentivize or reward universities. (DEA 2013) In light thereof, it is reassuring to follow efforts of the Danish Agency for Science, Technology and Innovation to develop a more nuanced approach to measuring knowledge exchanges (see e.g. Styrelsen for Forskning og Innovation 2015a).

[21] On a related note, Philpott et al. (2011) argued that a strong topdown push towards the ideal of the entrepreneurial university could actually reduce overall entrepreneurial activity in the university.

How should technology transfer be organized? Finally, DEA (2013) cautioned against pursuing "one size fits all"-models for organizing technology transfer activities, as the Danish universities differ widely in their relative collaboration profiles and approaches. Regardless of how technology transfer activities are organized, DEA (2013) pointed to the importance of ensuring that at least early-stage technology transfer functions are decentralized to the individual university and even, in relevant cases, to departments, research centers and large projects. This has to do with the importance of establishing personal ties between support staff and academic research and of supporting early-stage identification and maturation of promising research results with a view to their commercial exploitation.

A number of other recent publications have zoomed in on knowledge and technology transfer from Danish universities. For example, The Danish Productivity Commission (Produktivitetskommissionen 2013) also emphasized the importance of collaborative ties over IP-based technology transfer mechanisms such as patent licensing and spinout formation. The report also called for an effective division of labor between public and private research, implying that universities should focus on fundamental research and application-oriented research of a more generic nature, to minimize the risk that public investments in science mere crowd out private R&D investments without increasing overall R&D activity. This efficient division of labor also calls for productive ties between universities and industry, to help firms reap spillovers from public science. The report stated that university-developed knowledge should in so far as possible be made freely available to industry in order to maximize the societal payoff from investments in public science; however, firms who enter into R&D collaboration with universities should pay for universities' marginal costs associated with these collaborations. The report also pointed to problems in identifying the market value of university inventions and suggested replacing current regulations with a rule that prices should be determined based on universities' marginal costs. Finally, the report lamented the unnecessary complexity in contractual negotiations between universities and industries and called for simpler models, e.g. where universities are paid a lump sum for renouncing rights to IP that may emerge from particular collaborations, provided that this does not negatively impact academic researchers' possibilities for continued research on the same topic.

A recent government-commissioned evaluation of knowledge exchange in Denmark (Styrelsen for Forskning og Innovation 2014) focused on direct exchanges of knowledge between universities and businesses. The evaluation confirmed that university-business collaboration is, overall, increasing in volume and variety and concluded that knowledge exchange is a much higher priority for university managers than just a few years ago. Among other things, the evaluators recommended more focus from universities (including at the department and faculty level) on making collaboration attractive and career-rewarding for researchers, emphasized the importance of co-location of academic researchers and collaborating firms, and argued that there is insufficient collaboration between academia and Danish small and medium sized enterprises (SMEs). Finally, the evaluators pointed to the need to deal with resource strains in TTOs, provide access to proof of concept funds to support the translation of academic research results, strengthening the use of students as a resource in knowledge exchanges, and to investigate possibilities for placing more technology transfer activities in private, university-owned holding companies and for stepping up universities' provision of research-based knowledge services.

The Danish Council for Research Policy (2014) compared framework conditions for technology transfer in Denmark, Baden-Württemberg in

Germany, Finland, Ireland, Israel, the Netherlands, New Zealand, Singapore and Switzerland. The Council found no significant differences in the framework conditions of a nature and magnitude that could explain the perceived differences in technology transfer performance between Denmark and other similar countries.

Finally, Universities Denmark published a primer on knowledge exchanges between universities and industry (Danske Universiteter 2014), which highlighted the high degree of variety in – and synergies between – mechanisms for knowledge and technology transfer (as described in chapter 2). In particular, the report pointed to a substantial overlap between activities such as student-driven knowledge exchange (e.g. through student projects and student entrepreneurship), collaborative research, networking and researcher mobility. The report also highlighted two mechanisms, which are not specifically addressed in this review, but very important nonetheless: research-based services to the public sector and the provision of continuing professional development and education.

PROOF OF CONCEPT – THE MISSING LINK?

DEA (2013, 2016) argued that policymakers and universities in Denmark have largely underestimated the magnitude and difficulty of the task involved in bringing university inventions from the "lab" to the market. There is a long road from the validation of research results that is necessary to obtain scientific publication to the level of validation and de-risking necessary before firms and private investors can make an informed assessment of its commercial potential and much less invest in it. As mentioned in previous chapter, university-developed inventions are usually little more than lab scale prototypes, embryonic and at the frontier of scientific advancements (Jensen & Thursby 2001; Colyvas et al. 2002), and considerable risk is associated with their validation, further development and commercialization (Munari et al. 2015a). Private investors have limited incentive to invest at this stage, among other things because of asymmetric information and the high degree of uncertainty (Murray 1998, 2007). Moreover, universities often lack insight into the information requirements of private investors and may therefore not know how best to prepare and present an invention to possible investors.

However, a period of maturation, further development and validation is often needed before commercialization is possible, and requires close guidance from qualified industry profiles. The key to successful commercialization is often a close and possibly prolonged collaboration between researchers with a promising technology and possible users or investors from the private sector (DEA 2013). But researchers often lack the incentive to engage in such activities, among other things because they are not usually funded by research grants, because they typically offer no opportunities for generating scientific publications, and because they are not prioritized in many universities (Branscomb & Auerswald 2001; DEA 2016).

As such, a funding gap is likely to arise, whereby technology transfer activities and academic spinouts are unable to secure adequate funding from private sources (OECD 2013; Pasquini 2013; Swamidass 2013; Munari et al. 2015a).

Thus, many promising university inventions are believed to end up in a metaphorical "Valley of Death" (Ehlers 1998; Branscomb & Auerswald 2001, 2002; Auerswald & Branscomb 2003). The main explanation for why academic inventions fail at this early stage is due to a lack of capital, as first pointed out by Ehlers (1998, p.-40):

> ***…the limited resources of the federal government, and thus the need for the government to focus on its irreplaceable role in funding***

basic research, has led to a widening gap between federally funded basic research and industry-funded applied research and development. This gap, which …is becoming wider and deeper, has been referred to as the "Valley of Death".

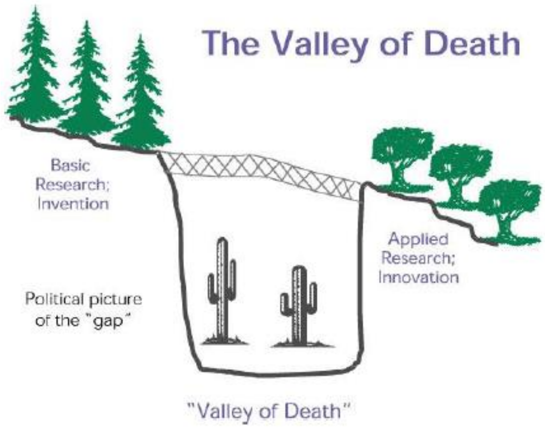
The US National Research Council (2007, p. 7) described the problem further as follows:

… The difficulty of attracting investors to support an imperfectly understood, as yet-to-be-developed innovation is especially daunting. Indeed, the term, "Valley of Death," has come to de-scribe this challenging transition when a developing technology is deemed promising, but too new to validate its commercial potential and thereby attract the capital necessary for its development. … Lacking the capital to develop an idea sufficiently to attract investors, many promising ideas and firms perish.

The metaphor refers to the "Death Valley" desert valley in Nevada, US (cf. figure 9). Branscomb & Auerswald (2001, 2002) proposed an alternative metaphor, that they argued is more accurate in describing the challenges that arise in the transition from research to innovation: "a Darwinian sea" (cf. figure 10) referring of course to Charles Darwin's theories about evolution and natural selection. Auerswald & Branscomb (2003, p. 228-229) argued that

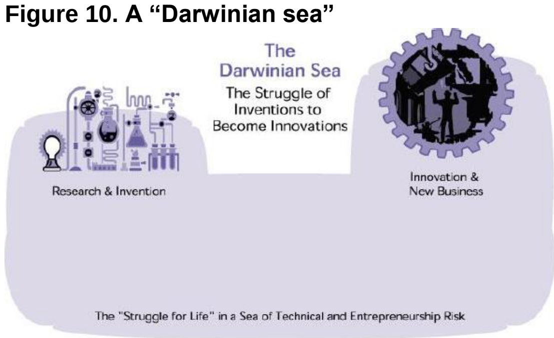
The imagery of the Valley of Death … suggests a barren territory when, in reality, between the stable shores of the S&T enterprise and the business and finance enterprise is a sea of life and death of business and technical ideas, of "big fish"' and "little fish" contending, with survival going to the creative, the agile, the persistent. Thus we propose an alternative image: the "Darwinian Sea".'

Figure 9. "Valley of Death"



Source: Ehlers (2000) in Branscomb & Auerswald (2002).

Figure 10. A "Darwinian sea"



Source: Branscomb & Auerswald (2002).

Whichever metaphor one prefers, the argued reason for the possible capital gap is asymmetric information: the inventors behind the new technology have deep and tacit insight into its possibilities and shortcomings; private investors need this knowledge to be able to make informed investment decisions, but lack sufficient insight. As such, they are likely to pursue more mature investments with lower levels of asymmetric information (National Research Council 2007). Meanwhile, projects at this stage are characterized by a high degree of uncertainty and risk, which are likely to reduce potential investors incentives to invest even further (Auerswald & Branscomb 2003).

Even when an innovation *has* demonstrated its technological and commercial potential, it can face difficulties in attracting the early-stage funding needed for its further development, to make the transition from prototype or early product to commercial success (National Research Council 2007).

Branscomb & Auerswald (2001) identified a number of other factors that may influence the ability to turn promising inventions into robust firms, including a lacking interplay between technology development and business development and a lack of access to complementary assets necessary for the successful commercialization of the invention e.g. supporting infrastructure, specialized production facilities, training of potential customers or users etc. (see DEA 2012 for an in-depth discussion of this).

It has been argued that the “Valley of Death” may function as a selection mechanism that separates weaker ventures from the most robust ones, allowing for subsequent resources to be concentrated on the most promising inventions (Beard et al. 2009; DEA 2012). However, several studies find or argue that there *is* a funding gap, which causes some otherwise promising university inventions and spinout ventures to fail (e.g. Auerswald & Branscomb 2003; Wessner 2005; Ford et al. 2007; Gulbranson & Audretsch 2008; Beard et al. 2009; Hall & Lerner 2010; Czarnitzki et al. 2011; European Commission 2014; FinKT 2015), thus legitimizing some form of public intervention. If innovative ventures that could have been successful fail because of lack of access to capital, this means that society is losing money on its investments in science and technology (Ford et al. 2007; Beard et al. 2009).

The stage where university inventions are validated and matured is often referred to as the “proof of concept” stage, as the aims of the stage are to demonstrate that results achieved in the university lab can be replicated under more complex, full-scale conditions in industry. More precisely, the aim is, according to Munari et al. (2015b, p. 9),

> ***… to evaluate the technical feasibility and commercial potential of early-stage university/PRO ideas and technologies and to demonstrate their value to potential industrial partners and investors.***

Typical activities during the proof of concept, or PoC, stage are purchase of external assistance to assess the technological or market potential of the invention, undertake experiments, develop “mockups” or early-stage prototypes, clarify IP positions, develop a business case, purchase or access necessary equipment, buy out researchers’ time (to allow them to work on the project), and, possibly, hiring temporary staff. Focused validation and maturation of the invention can bring to a point where private firms and investors can perform a satisfactory assessment of its potential. (DEA 2016)

Studies have shown that achieving proof of concept for university-developed inventions and technologies and strengthening spinouts’ ability to build convincing business cases is key accessing funding from early stage investors (Wright et al. 2006).

In a study of spinouts based on inventions assigned to the University of Michigan from 1999 to 2010, Gubitta et al. (2015) showed that gap funding provided through the university TTO had an important signaling effect, positively affecting firms’ chances of attracting venture capital and thus, indirectly, their subsequent growth. These findings were obtained after controlling for spinouts’ technological endowment, the founders’ human capital, and resources in its network. The authors therefore described university-supplied gap funding as “an effective signal of the quality and credibility of a new business” that venture capitalists use in their decision regarding which ventures to invest in. On a related note, a study of European early stage venture capital investment managers indicated that venture capital funds are more positive towards investing in spinouts that have already received capital from public sources[22] (Knockaert et al. 2010), presumably because it allows for risk sharing, because public funding serves a signal of the quality of the venture, and/or because both public and private investors invest in the best (or at least similar types of) ventures.

On a side note, based on US data, Hayter & Link (2015a) found that universities affiliated with a proof of concept center have positive and statistically significant increase in the number of spinoffs established each year after adoption.
However, PoC funding is likely to be more important for some inventions than others. For instance, Kotha et al. (2013) argued that different inventions entail different costs of commercialization, and that interdisciplinary research in particular is likely to involve greater coordination costs in the patenting and commercialization process, especially when the research involves distant scientific domains and/or when the team has limited experience in working together or in developing inventions with a view to their commercial exploitation. These coordination costs arise, the authors argued, from the need for the members of the inventor team to develop the invention to the point of transfer, and to engage with the licensee firms to ensure the successful transfer of the invention and underlying knowledge. Kotha et al. (ibid.) showed that anticipated coordination costs influence whether or not the invention is licensed, which opens the door for considering public intervention.

So should universities and governments fund proof of concept studies? Many do, in Europe and in the US (Keating 2013). However, the mix of instruments and overall approach to supporting the commercialization of academic research differs significantly from country to country (Munari et al. 2015). However, one recurring feature in many countries is that universities and other public research institutions are complementing government funding for start-ups by setting up their own proof of concept and seed funds (OECD 2013). Some of the lessons learned from these initiatives are discussed by Gulbranson & Audretsch (2008) and Hayter & Link (2015b).

Denmark had a national proof of concept fund during the period 2006 to 2012, but this fund was closed down and responsibility for funding PoC studies was given to universities, with varying results. Moreover, while it makes sense for universities to fund early-stage PoC studies, it is usually not within their grasp to fund later-stage, more costly PoC studies. A discussion of proof of concept funding in Denmark can be found in DEA (2016), which argued that there is a need to discuss whether there is today sufficient funding available to bring promising university inventions to a point where they become attractive to private investors.

[22] It is interesting to note that Sternberg (2014) found that government support had little if any impact on the success of university spinouts.

7. ACADEMIC SPINOUTS

ACADEMIC SPINOUTS 101

In their efforts to generate new revenue streams and to meet a political demand for more innovative firms, universities are increasingly – albeit to varying degrees – looking for possibilities to start new firms based on their research outputs (Wright et al. 2006; Bigliardi et al. 2013). Their incentives to do so have been further reinforced by a heavy emphasis among policymakers on measuring universities' spinout performance.

Many universities are therefore increasingly interested in taking equity in a company in exchange for the rights to use university intellectual property (Feldman et al. 2002) as an alternative to licensing or selling the IP. This is understandable, as it removes the need to maintain the IP and to engage in expensive post deal management with licensees.

The popularity of academic spinouts among policymakers can also be credited to a belief that they are suitable and effective vehicles for advancing the industrial application of scientific knowledge and, simultaneously, creating jobs and growth on the local level (e.g. Carayannis et al. 1998; Bigliardi et al. 2013). In addition, many universities see equity ownership in promising spinouts as a desirable alternative to trying to generate income from licensing embryonic technologies (Siegel et al. 2003c), particularly when inventions are characterized by high degrees of uncertainty and therefore unlikely to attract interest from serious potential licensees (Etzkowitz 2003) or when a high degree of tacit knowledge implies that successful commercialization is contingent upon active participation from the academic inventors (Shane 2004a).

In addition, equity investments in spinouts are likely to generate higher revenues than sale of IPR or royalty payments from licensing agreements (Jensen & Thursby 2001). In fact, Bray & Lee (2000) found that spinouts create a tenfold increase in income compared to licensing agreements and therefore suggested that licensing should only be the preferred option when the invention is not suitable for development in a spinout company.

University spinouts or spinoffs are, according to Bigliardi et al. (2013, p. 178):

> ***start-up companies that are founded by an academic inventor with the aim to exploit technological knowledge that originated within a University setting in order to develop products or services.***

They are thus high-tech companies in business in order to commercialize the results of scientific or technological research (Shane 2004a).[23]

The term "spinout" or "spinoff" refers to the fact that the company is founded, at least in part, by individuals who were employed at the parent university, and/or based on scientific or technological results developed at the university and subsequently transferred to the spinout (Smilor et al. 1990; Roberts & Malone 1996; Carayannis et al. 1998; Nicolau & Birley 2003).

Academic spinouts are thus a means of transfering technology from the parent university to themselves and, subsequently, to the market via their product offering (Carayannis et al. 1998; Bigliardi et al. 2013).

[23] As Abreu & Grinevich (2013) pointed out, university spinouts can be either based on technological inventions or set up consultancy businesses. In this chapter, we focus on spinouts based on academic inventions.

However, spinouts are not always based on codified research findings from the university; in fact, Karnani (2013) argued that more than half of university spinouts are based instead on tacit knowledge, essentially "byproducts on the path to scientific discovery.

There are large differences in spinout activity and motivations in different scientific fields (Aldridge et al. 2014). Spinouts are most prominent in science based and high text industries e.g. biotechnology, medical technologies and information technologies (e.g. Shane 2004a, 2004b; Bigliardi et al. 2013). For example, biotechnological research often lends itself well to commercialization via spinouts because of the discrete nature of the inventions and the long time needed to develop them into market-ready products (Owen-Smith and Powell 2001b; Shane 2004a). However, even within sectors, inventions differ as to whether or not spinouts are the optimal vehicle for commercialization. According to Shane (2004a), key parameters in determining whether a spinout is appropriate include the effectiveness of patents in protecting the invention and building a strong patents portfolio, the importance of complementary assets for the exploitation of the invention, the age of the industry, the degree of market segmentation and the average firm size.

Finally, most research on the role of universities in spinning out new firms focuses on firms established by university staff, but students and graduates are also important sources of spinouts from university research (Pirnay et al. 2003; Boh et al. 2015). For instance, Åsterbro et al. (2012) examined start-up activity among recently graduated students from U.S. universities and found, among other things, that the gross flow of start-ups by recently graduated students with an undergraduate degree in science or engineering is at least an order of magnitude larger than the spin-offs by their faculty, and that the graduates' spin-offs are – contrary to popular perception – not of low quality. The authors argue that focusing on spinouts developed by faculty might not be the most effective way for universities to stimulate entrepreneurship and economic development

In addition, direct spinouts from the university account for only a part of universities' contribution to small firms. Shah & Pahnke (2014) argued that universities also give rise to startups that do not directly exploit knowledge generated within academic laboratories, even though they may have been based on knowledge gained within university environments. The authors mention two examples from Stanford University: Google, which was based on efforts to commercialize a technology developed within an academic lab, and Instagram, which was not yet benefited a lot from entrepreneurship education initiatives at Stanford University.

WHO IS INVOLVED IN A SPINOUT?

There are four key types of actors involved in a spinout (Rogers & Malone 1996; Carayannis et al. 1998). First, *the inventors or originators of the technology*, who developed it to the point where it could be transferred to the spinout. Indeed, participation of the inventors has been shown to be positively associated with the speed of commercialization and the subsequent income from the technology (e.g. Markmann et al. 2005b). Second, *the entrepreneurs* who are responsible for creating the new venture and for developing marketable products or services based on the technology. Third, *the parent university,* in which the technology was created and matured, and which will also often provide resources and support, e.g. in connection with IPR protection and transfer of IPR, but also potentially venture funding, advice, workspace, access to equipment etc. (see also Rappert et al. 1999; Steffensen et al. 2000). Finally, *the private investors* who provide the funding – and typically also commercial expertise – needed to establish the firm and develop the technology into marketable products.

The inventors may choose to join the spinout firm, to stay employed in the university but maintain ties to the firm e.g. in an advisory capacity, or to leave the development of the technology and firm entirely to third parties (Bigliardi et al. 2013). Inventors and sometimes also the parent university may hold stake/equity in the firm, as will additional external investors (Carayannis et al. 1998).

Parent universities may choose to play very different roles in the spinouts their researchers establish, based on, among other things, their objectives in creating spinouts and the resources available to support them (Clarysse et al. 2005).

Academic spinouts are relatively complex phenomena, because of the considerable number of and variation in parties involved – from researchers and students to university managers, research funders, TTO staff and various external investors and other stakeholders – and because of possible conflicts of interest between these parties (Birley 2002).

Empirical studies have moreover suggested that most spinout firms go through a similar set of phases (see e.g. Ndonzuau et al. 2002; Vohora et al. 2004; Vanaelst et al. 2006; Helm & Mauroner 2007):

- A “pre spin-off” phase, which involves undertaking research, screening, identifying and framing commercial opportunities, and demonstrating both the scientific/technological and business case,
- A “spin-off establishment” phase, where the actual company is established and activities launched, and
- A “post spin-off phase”, where the maturing firm begins production and sales and is re-oriented and re-organized as a larger, more established firm (though not necessarily in that order).

ACADEMIC ENTREPRENEURSHIP IS DIFFERENT FROM PATENTING OR COLLABORATING WITH INDUSTRY

The effort to commercialize an invention derived from university research typically starts in the university setting, at which the inventor-researchers are employed. As such, the initial stages of development of the invention and the spinout are subject to protocol and procedures at the university. This can in some cases hinder progress of the venture (Berbegal-Mirabent et al. 2007). It could however also be argued that the university can function as an incubator of sorts, a safe place to start, close to the research environment from which the firm originated.

Keeping the inventor academics involved in the new venture allows for a more effective transfer of technology to the spinout (Roberts & Hauptman 1986). In fact, Thursby and Thursby (2001) argued that, because of the embryonic nature of most university research, the technology is usually no more than a laboratory scale prototype, requiring substantial further development, dependent at least in part on tacit knowledge from the academic lab; as such, successful commercialization often depends on the involvement of faculty inventors in further development efforts. They also showed, however, that faculty members generally have very limited incentive to engage in such efforts. Starting a company is however substantially different for the academic inventor than e.g. taking out a patent or engaging in collaboration with industry. The stakes are higher, and the transition greater (e.g. Colyvas & Powell 2007), particularly as the academic inventor will often be directly involved in the company in some capacity.

Aldridge & Audretsch (2011) examined why some scientists become entrepreneurs while others do not. They found that research on entrepreneurs in general offers only to a limited extent applies to academic entrepreneurs. For example, personal characteristics and human capital, which have been shown to be important general determinants in the decision to become an entrepreneur, were not useful in identifying academic entrepreneurs. However, the study showed social capital, as measured by linkages to private industry, to be an important factor in increasing the likelihood of a scientist becoming an entrepreneur. Having ties to other scientists working in industry and having served on a company scientific advisory board were shown to be particularly conducive to academic entrepreneurship. On a related not, Shane & Stuart (2002) found that university spinout founders' who were related to venture capitalists were less likely to fail.

Many spinouts start on a part-time basis, as the founding retain their university positions (Doutriaux 1987; Roberts 1991a), at least for a while. Also, many of the members of the founding team often know each other beforehand from their university work (Clarysse & Moray 2004), and founder teams in university spinouts therefore tend to be composed of relatively similar individuals (Colombo & Piva 2012). All in all, this means that academic spinouts have competences and resources that differ significantly from those of other, non-academic startup firms. According to Colombo & Piva (2012, p. 81):

> ***They have greater (and more effective) scientific and technological competencies than their non-academic counterparts, but smaller (and less effective) commercial and managerial competencies.***

Indeed, Ensley & Hmieleski (2005) found that university-based start-ups have more homogeneous top management teams than independent start-ups, and that they also exhibit significantly poorer performance as indicated by net cash flow and revenue growth.

The literature often points out that most researchers are neither particularly interested in or suited for the life of an entrepreneur, because of their decision to enter into academia and the types of skills and experience that they have accumulated during their academic career. (e.g. Clarysse & Moray 2004; Berbegal-Mirabent et al. 2007; Colombo & Piva 2012). While valuable in the university setting, these competences are likely to differ significantly from those necessary to successfully develop and market science-based inventions and to establish viable science-based firms (Chiesa & Piccaluga 2000; Bathelt et al. 2010).

Many studies have demonstrated the importance of the management team for both the performance of a venture and its ability to attract venture funding (see e.g. Clarysse & Moray 2004). In particular, business competences are crucial in securing external funding, ensuring an effective, commercially driven development process, and evolving into a mature, professional firm (Clarysse & Moray 2004).

But many researchers have little or no experience working full-time in industry (Chiesa & Piccaluga 2000; Clarysse & Moray 2004; Vohora et al. 2004; Colombo & Piva 2012), and they generally lack commercial skills and networks to the market and to private investors (Mosey & Wright 2007).

Colombo & Piva (2012) compared founding teams and strategic choice for academic and non-academic new technology-based firms in Italy and found that academic startups have an advantage in hiring qualified scientific and technical staff, but are less likely that non-academic start-ups to hire people with a commercial background. They are also more likely than non-academic firms to engage in alliances with public research organizations, to purchase technical services from them, and to participate in pre-competitive international collaborative research projects.

However, in the case of academic spin-outs, the level of scientific and technological complexity is often very high and at least partly dependent on the tacit knowledge of the inventors. Technical development is an important part of the CEO's duties, and the CEO needs to be able to understand the technology; it is therefore often very difficult and potentially detrimental to the initial development of the technology to hire an external CEO at the start of the venture (ibid.). The authors therefore suggest coaching or otherwise guiding the founding team to compensate for their lack of commercial insight.

HOW DO ACADEMIC SPINOUTS FARE?

Academic spinouts are highly heterogeneous in terms of e.g. their resources, their business models and the institutional settings from which they emerge (Wright et al. 2006).

Researchers have pointed out that spinouts that originate in the academic environment may not always be based on a selection of the best ideas, i.e. the ideas with the greatest commercial potential, because they may lack the insight and the competition for resources that exists in more developed high-tech entrepreneurial environments such as Boston or Silicon Valley (Clarysse et al. 2005).

Nonetheless, university spinouts face similar difficulties as other science and technology-based start-up firms (Oakey et al. 1996). As such, they are also highly prone to failure. Despite a substantial focus on and increase in university spinouts over the past decades (Djokovic & Souitaris 2008), the financial results from these science-based firms have so far been, overall, low (Shane 2004a; Siegel et al. 2003c). Colombo et al. (2010) argued, however, that even though most university spinouts are not high-growth "gazelles", the knowledge or technology they create may still make a significant contribution to the innovativeness of their customers or be transferred to and exploited by other companies (through e.g. partnerships or acquisitions).The authors therefore call for more insight into the role that university spinouts play for the dynamic efficiency of the economic environment which they are a part of, and particularly of the positive externalities that such firms may have.

Vincett (2010) estimated the lifetime impacts of Canadian academic spinouts in the non-medical natural sciences and engineering, that were based directly on research performed in 1960–1998. These impacts were compared to the impacts of all government funding, direct and indirect, over the same period. The author shows, first, that successful spin-offs grow (often exponentially) over several decades, and, second, that - even with very conservative assumptions, and allowing for the time value of money - the impacts exceed government funding by a substantial margin. The author moreover argued that these impacts provide justification for the public investment in academic spinouts,

In light of these findings, it is important to remember that there may be several motives for starting an academic spinout, only one of which is profit. Spinouts can however also be seen as a tool to facilitate the dissemination and transer of university research, and thus contribute primarily indirectly to the economy, by spreading their technology to other firms (Rasmussen & Wright 2015). On a related note, Hayter (2011) showed that academic entrepreneurs themselves define success in a number of complex, interrelated ways including technology diffusion, technology development, financial gain, public service and peer motivations, among others. The author also concluded, based on in-depth personal interviews with academic entrepreneurs, that a large number of entrepreneurs show little immediate interest in growth and that they founded their firms to pursue other sources of funding for developing their research and its applications (rather than to pursue profit and growth per se).
However, at the end of day, high-tech firms are usually dependent on external investors, and these investors need to see a return on their investment. As such, it is unlikely in practice that

many academic spinouts will operate without seeking to become profitable.

Nonetheless, spinouts appear to have little impact on local or regional economic development (Harmon et al. 1997; Mustar et al. 2008). Moreover, most of these firms remain small (Degroof & Roberts 2004) and grow less than other high-tech companies (Ensley & Hmieleski 2005). This has generated interest in understanding the challenges and pitfalls that university spinouts meet (Wright et al. 2006). In addition, focus has shifted in many universities from maximizing the number of spinouts created to strengthening the starting point for these companies' future results and value (Lundqvist & Hellsmark 2003; Moray & Clarysse 2005; Wright et al. 2006).

Based on insights from spinout companies, university TTOs and venture capital firms in the UK and Continental Europe, Wright et al. (2006) examined perceptions of university spinouts and other high-tech venture capital firms and found evidence of a gap between the demand for early-stage finance from entrepreneurs and TTOs on the one hand, and the willingness of venture investors to invest in that stage on the other. More precisely, venture investors prefer to invest in spinouts after the seed stage, particularly once proof of concept has been achieved. A similar gap has been identified in the US (Shane 2004a).

Wright et al. (2006) point out that this challenge may be compounded by a lack of understanding in the university of the requirements of potential external funders. For example, university staff often lack familiarity with the information requirements and constraints that venture investors operate under, or with the level of preparation needed for investors to be able to easily assess the potential value of a university venture. As a results of these shortcomings, university spinouts may face added difficulties in attracting venture funding (ibid.). For a more in-depth discussion of the role of proof of concept funding, please see chapter 6.

Some of the factors that are particularly important for investors are, according to Wright et al. (2006, p. 495):

> ***The availability of a stock of technology to be exploited, external expenditure on intellectual property protection, an experienced technology transfer team and business development capabilities.***

The authors moreover stressed the importance of a strong portfolio of patents, which includes procedural, application and product claims, typically spread over different patents. However, Wright et al. (2006) also pointed out that the importance of patents can be overstated; e.g. in software development and services, patents and other forms of intellectual property are far less important than in e.g. biotech and electronics, and it is instead key to be able to scale up a prototype. However, the authors pointed out, TTOs are often less prepared to support such activities.

The importance of founding or management teams for the performance of an academic spinout has also been stressed by e.g. Visintin & Pittino (2014) and Diánez-González & Camelo-Ordaz (2015). Other work has confirmed the importance of good networks to venture capital investors networking capabilities (Lockett et al. 2003, 2005; Walter et al. 2006; Soetanto & van Geenhuizen 2015). Wright et al. (2006) pointed to the need to strengthen personal ties and mutual understanding between relevant university personnel and key private investors, but also successful entrepreneurs and established firms, in order to overcome cultural differences and gain greater insight into needs and procedures in private sector commercialization efforts. Murray (2004, p. 643) emphasized that academic founders have two networks that can both bring important social capital that can be transferred to the spinout firm:

> ***… the academic's local* laboratory network *– a network to current and former students and advisors established by the inventor through his laboratory life. The second form of social capital is a wider,* cosmopolitan network *of colleagues and co-authors established through the social patterns of collaboration, collegiality and competition that exemplify scientific careers.***

A study by van Geenhuizen & Soetanto (2009) points to the need to study the performance of academic spinouts at various stages of their development. For example, their study of spinouts from Delft University of Technology showed that spinout firms' ability to overcome obstacles to growth differs depending on firm age. On a related note, Ortín-Ángel & Vendrell-Herrero (2014) found that the (often documented) financial underperformance of university spin-offs disappeared after two or three years of operation.

Finally, several studies point to the importance of the parent university or organization for spinout performance. Rasmussen et al. (2014) even emphasized the role of the home department, as they found that even small differences in initial departmental support to a spinout from management and senior academics were seen to have a major impact upon the subsequent development path of the spinout. The authors also found that a lack of departmental support severely constrained the development of a new spinout. These findings point to the importance of gaining greater insight into the role of the parent organization, all the way down to the specific departments involved in a spinout venture

WHAT MATTERS FOR SPINOUT FORMATION?

Berbegal-Mirabent et al. (2015) examined antecedent conditions that are associated with a higher number of university spinoffs using qualitative data from 63 Spanish universities. Overall, they found that there is not one "recipe" for creating spinouts but rather several possible approaches: "universities can adopt different strategies yet achieve similar results." (ibid, p. 2277). For example, the presence of an incubator or dedicated programs to support academic entrepreneurship may promote the establishment of spinout firms; but a university without such dedicated infrastructures may still be successful in churning out new firms.

In the following sections, we examine current evidence on the role of various factors for the performance of spinouts, in addition to the obviously crucial access to capital discussed in the previous section.

The role of the entrepreneur. How many scientists actually found a spinout? Canadian data suggest about 17 pct. (Landry et al. 2006) and a US study found similar numbers (Fini et al. 2010). While figures may vary significantly across universities and countries, these figures indicate that a sizeable proportion of scientists, at least in North America, are engaged in spinout formation.

Goel & Grimpe (2012) pointed out that there tends to be a general and often implicit assumption in the literature that academic entrepreneurs become entrepreneurs in order to commercialize their research and they show that this assumption is often not justified.

Regardless, several studies highlight the importance of the characteristics, competences and experience of the founders in determining the performance of a spinout firm (Phan & Siegel 2006; Helm & Maurorer 2007; Clarysse et al. 2011b; Venturini et al. 2013)
As previously mentioned, because of the academic origin of the founders, it is also important to ensure that the founders have sufficient access to relevant and qualified entrepreneurial

knowledge and skills (Smilor & Matthews 2004; Clarysse et al. 2005).

A crucial factor for the success of a new venture is the commitment of the founder scientists (Vohora et al. 2004). However, as discussed in chapter 3, many scientists have limited motivation to leave the university to actively pursue the commercial exploitation of their research (e.g. Lockett et al. 2003). This lacking motivation is reinforced by the fact that many universities do not reward commercialization and spinout activities in their promotion and tenure decisions (Siegel et al. 2003b). It has been suggested that giving academic inventors a larger share of the equity in the firms they help found might strengthen incentives to invest their time in establishing firms (Lockett et al. 2003).

Recent work also underlines the importance of the social networks of the academic inventor-entrepreneur. For example, Hayter (2016) pointed to the importance of social networks among academic entrepreneurs for entrepreneurial development. More precisely, he found that academic networks are important for the initial establishment of a spinout form, but may constrain subsequent entrepreneurial development. Hayter (ibid.) also pointed to the importance of boundary spanning individuals who help socialize academic entrepreneurs to market-oriented motivations, values, and practices, and to individuals that can pave to way to new contacts who can provide funding and additional contacts for the spinout. On a related note, Breschi & Catalini (2010) pointed to the importance of individuals who both publish scientific articles and invent patents as gatekeepers who bridge the boundaries between academics and inventors. They also found that these individuals, who usually hold prominent positions, tend to have either a very central position in the scientific *or* the technological networks. Moreover, their data showed that corporate scientists are more involved in bridging the world of science and technology in the US than in Europe.

Finally, characteristics of scientists' academic research work may influence their opportunities to become entrepreneurs: D'Este et al. (2012) found that making contributions to the pool of technological opportunities is driven by academic scientists' research excellence, while exploitation of entrepreneurial opportunities driven by previous collaboration with industry partners, scientific breadth and experience of technological discovery.

The role of the parent university. O'Shea et al. (2005, 2008) showed that spinout creation is highly skewed in US universities, meaning that a small number of institutions (notably MIT) generate a very large proportion of the total number of spinouts from American universities. Similar findings have been shown for UK universities (Lockett & Wright 2005; Wright et al. 2007).

Some studies have suggested that university-specific characteristics can help explain inter-university differences in spinout activity (Mustar et al. 2006; Djokovic & Souitaris 2008).

Rasmussen & Wright (2015) pointed out that nurturing spinouts is a complex challenge requiring support from all levels of the university, from the individual scientist and research group, to the department, university management, the TTO, and other support infrastructure – and from many external actors in industry and the public sector.

Among other things, the university's policy on intellectual property is likely to influence academics' motivation to engage in patenting and spinout activities (DiGregorio & Shane 2003; Lockett & Wright 2005; O'Shea et al. 2005), as is the transparency and clarity of policies for supporting entrepreneurs (Smilor & Matthews 2004) and the existence of a culture supportive of entrepreneurship (Clark 1998). Indeed, based on a survey of university professors in Sweden and Germany, Sellenthin (2009) showed that the support infrastructure at the university has a positive impact on researchers' incentives to apply for patents, and that researchers who have previously engaged in patenting are much more likely to patent again.

On a related note, Muscio et al. (2016) investigated the impact of internal university regulations on academic entrepreneurship on Italian universities' institutional capability to generate new ventures and found, among other things, that monetary incentives do play a significant role in promoting spinout activity among academic researchers. They also concluded that overly-restrictive university rules regarding contract research can have a negative impact on the creation of spinout firms by academics.

Other studies indicate that the stock and combination of resources in a university are also important in explaining variation in universities' spinout activity (Feldman et al. 2002; Link & Scott 2005, O'Shea et al. 2005). Others have pointed to the importance of the R&D intensity of the university (Lockett et al. 2005).

Di Gregorio & Shane (2003) showed that institutional characteristics influence the number of spinouts they produce, notably the department's intellectual eminence, the amount of externally sponsored funds and the type of university licensing policies. By comparison, O'Shea et al. (2005) found that spinout formation was associated with historical dependence, faculty quality, size and orientation of science and engineering funding, and commercial capability.

Lockett & Wright (2005) found that both the number of spinout companies created – in total and with equity investment– are significantly and positively associated with the university's expenditure on intellectual property protection, the business development capabilities of the TTO and the royalty regime of the university. Their findings underline the importance of developing (or otherwise gaining access to) business development know-how.

Several studies moreover argue that receiving funding or other support (e.g. mentoring and training) from the parent university, and maintaining strong to the university, are important factors in the survival or performance of spinouts (Roberts 1991b; Lindelöf & Löfsten 2004; Smilor and Matthews 2004; Vohora et al. 2004; Lockett et al. 2005). For instance, Rothaermel & Thursby (2005) found that spinouts with strong ties to their parent organizations were less likely to fail but also less likely to successfully "graduate" within a timely manner.[24] This may be particularly important as most academic spinouts tend to locate and remain close to their university (Zhang 2009). However, the links between academic spinouts and their parent university vary widely (Miner et al. 2012).

The relationship to the parent organization is also one of several factors that can influence the speed of transfer. Müller (2010) analyzed the length of the time period between a founder leaving academia and the establishment of his or her firm. The author found that longer time lags were caused by the need to assemble complementary skills, either by expanding the skills of the founder or by identifying new members of the founding team. However, the venture is established more quickly there has been high-level technology transfer, if founders have access to university infrastructure, or if they receive informal support from former colleagues.

Interestingly, even though academic spinouts tend to remain small and their overall performance has yet to live up to policymakers' expectations, it appears that their failure rates are

[24] In contrast, Slavtchev & Göktepe-Hulten (2015) found that support in the early stage by the parent organization - e.g. in developing a business plan and in acquiring external capital - can speed up commercialization. support in the early stage by the parent organization - e.g. in developing a business plan and in acquiring external capital - can speed up commercialization.

lower than for the overall population of startups (see e.g. Degroof & Roberts 2004; Djokovic & Souitaris 2008). However, as Djokovic & Souitaris (2008, p. 241) point out, “it is inconclusive if the higher survival rates of spinouts can be attributed to higher fitness of [spinouts] or rather to support systems of their parent organization that are keeping them ‘alive’”. For example, Ensley & Hmieleski (2005) showed that although academic spinouts may be better survivors than non-academic startups, they may exhibit poorer financial performance, e.g. as indicated by cash flow and revenue growth.

However, using a large database on US venture-backed start-up companies, Zhang (2009) showed that although university spin-offs have a higher survival rate, they do not differ significantly from other start-ups in terms of the amount of venture capital raised, the probability of completing an initial public offering, the probability of making a profit, or the size of employment.

It is worth nothing that a large proportion of university spinouts are not based on intellectual property formally disclosed to the university (Fini et al. 2010; Aldridge and Audretsch 2011), prompting scholars to theorize on how faculty members' incentives for disclosing inventions could be enhanced, e.g. by allowing faculty scientists to self-license their invention (Panagopolous & Carayannis 2013).

When inventions are not disclosed, the role of the parent university is naturally expected to be much smaller if it has a role to play at all. This also implies that spinout data may underestimate the actual contribution from universities to the establishment of new firms (Aldridge & Audretsch 2011). On a side note, whether or not scientists disclose their inventions to their parent university appears to be linked to how the invention is subsequently commercialized: using data from university scientists funded by the National Cancer Institute at the US National Institute of Health (NIH), Aldridge & Audretsch (2010) found that the 70 pct. of scientists who disclosed their inventions to the university TTO were more likely to commercialize via licensing, while the 30 pct. who chose the “backdoor route to commercialization” by not disclosing their invention were more likely to found a spinout.

The role of the TTO. TTOs can play an important role in supporting spinout creation by identifying inventions that could form the basis of a new company, by aiding with IPR protection and transfer, and by supporting inventors and founders in the early maturation and transfer of the invention (Djokovic & Souitaris 2008).

Both the size and the level of experience (particularly in business development) of a TTO has been found to be positively associated with spinout activity (Smilor & Matthews 2004; Lockett et al. 2005; Lockett & Wright 2005; Powers & McDougall 2005).

However, other scholars have suggested that TTOs lack the necessary skills to identify and support inventions with strong commercial potential (Lockett & Wright 2005; Siegel & Wright 2007), and that academic researchers may therefore even try to circumvent TTOs by establishing links of their own to commercial actors (Mosey & Wright 2007). It has been suggested that universities can access commercial expertise via experienced professionals that are affiliated with the university on a part-time basis to provide guidance for the TTO and for inventors; however, it can be difficult for a university to identify enough professionals with the necessary qualifications, largely because of their limited networks to the commercial sector (Franklin et al. 2001).

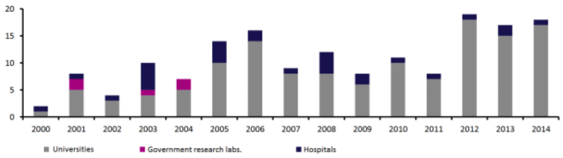
Finally, many universities develop incubators and science parks to support the development of newly formed and/or established research-based firms. In the next chapter, we review the literature on incubators and science parks. Also, a handful of universities have set up their own venture capital or private equity funds, for example DTU Innovation A/S at the Technical University of Denmark. Such university-managed funds are rare and understudied in the literature, although one recent study (Croce et al. 2014) has tried to remedy this by describing European and US university-managed funds. The study identified a number of structural and performance-related differences between European and American funds, though these differences may, according to the authors, be at least partly explained by the different stages of development or maturation of the overall venture capital markets in the two geographical regions.

Interestingly, Munari et al. (2015a) found that European public research spinout firms were likely to attract more follow-on funding and investors when they were financed by seed funds managed *internally* by a university or other public research organization, and when they were linked to universities with high scientific rankings. Their study suggests university-managed seed funds may by particular beneficial for academic spinouts, at least in their attempts to raise additional funding.
O'Shea et al. (2008) summarized the key factors that influence university spinout activity and its impact on society, cf. figure 11.

SPINOUTS FROM DANISH UNIVERSITIES

There has been a substantial increase in the number of spinout firms established by Danish universities since 2000 (figure 11). Approximately 50 spinouts were created in the period 2012-2014, compared to about 100 spinouts during the period 2000-2012 (Styrelsen for Forskning og Innovation 2015a). By far the most prolific university in generating spinouts is the Technical University of Denmark (DTU).

Figure 11. Number of spinout companies 2000-2014, based on type of parent organization



Source: Styrelsen for Forskning og Innovation (2015a). Note from the authors of the figure: The number of spinouts established before and after 2012 cannot be compared, due to a change in the definition of spinouts used in 2012.

Recent years have seen several initiatives to boost the number and viability of Danish academic spinouts, including e.g. Copenhagen Spin-Outs, a collaboration between Danish public research institutions, research parks, firms and investors to increase the number of biotechnological spinouts in the Capital Region of Denmark.

The effects of these initiatives remain to be seen, but it cannot be ruled out that they have played a role in the recent increase in the number of spinouts. However, robust evaluations are needed to examine their results and especially their long-term impact on the number and performance of Danish spinouts.

8. FORMAL AND INFORMAL COLLABORATION

As mentioned in chapter 2, university-interaction can take many firms, not just IP licensing and spinout creation but also e.g. joint R&D projects, consulting, contract research, conferences and informal information exchange.

Collaborative and informal ties are generally valued higher than patenting, licensing and spinouts as mechanisms for the transfer of academic knowledge, by firms (Cohen et al. 2002) and academic researchers alike (Agrawal & Henderson 2002). Formal and informal collaboration are crucial in facilitating the exchange of ideas and knowledge and providing access to research materials, equipment and funding (Roessner 1993; Klofsten & Jones-Evans 2000; Schartinger et al. 2002; D'Este & Patel 2007; Link et al. 2007).

Motoyama (2014, p. 39) studied long-term collaboration on nanotechnology development between university and industry in Japan, and emphasized the importance of less explicit and more informal collaboration

> ***… university and industry collaborate at a deep level, integrates various disciplines of knowledge, and university functions as a hub to develop networks of researchers, and to train corporate researchers to acquire the epistemological thinking process, much more than to transfer technologies.***

This chapter reviews current insight into some of the main channels for knowledge exchange not covered in chapters 6 and 7 of this report.

COLLABORATIVE RESEARCH

As mentioned in chapter 2, collaborative research, or joint R&D, refers to formal collaborations with the aim of cooperating on specific research and/or development projects (Hall et al. 2001; D'Este & Perkmann 2011).

Many of the collaborations in this category can be described as "pre-competitive" and often receive public co-funding (D'Este & Perkmann 2011). They may also cover purely industry-sponsored research (Roessner 1993).

Collaborative research is far more common among academic researchers than participation in patenting or startup activities (D'Este & Patel 2007; Perkmann & Walsh 2007).

Like other forms of university-industry interaction, collaborative research often builds on long-lasting personal relationships (Bishop et al. 2011). The interplay between formal interaction and informal, personal interaction appears to be crucial to effective university-industry ties, presumably because they help to build insight and trust between parties, while casual meetings allow for a free-flowing exchange of ideas and knowledge from which new ideas for research projects can blossom. As such, informal, face-to-face interactions is vital to build strong, lasting formal research agreements (Kogut 2000).

According to Franzoni & Lissoni (2006), collaborative ties like contract research or consultancy work can act as a first step or gateway to more extensive and/or long-term collaboration.

CONTRACT R&D AND CONSULTING

Contract research refers to original research, which is commissioned and paid for by one or more firms and therefore takes its point of departure in specific problems and interests in industry. As such, the research undertaken is often more applied than other forms of collaborative research (Poyago-Theotoky et al. 2002; Van Looy et al. 2004).

This is supported by a study of university-industry interaction in Austria (Schartinger et al. 2002), that showed that collaborative and contract research are used to serve different needs, as firms that use more of one form tend to use less of another.

Many academics also provide *consulting* to industry. This includes research or advisory services commissioned and paid for by one of more firms (see e.g. Perkmann & Walsh 2008) and appears to be a key factor in knowledge transfer between universities and industry (e.g. Cohen et a. 2002; Thursby & Thursby 2011). Some universities even encourage their staff to engage in consulting (Schmoch 1999).

Firms may choose to engage academic researchers as paid consultants to e.g. gain access to tacit expertise or knowledge, which is difficult or prohibitively expensive to codify, to access expert academic judgment to examine in-house R&D options and challenges (Perkmann & Walsh 2008), and because this mechanism allows for clear assignment of IP rights. However, much consulting activity is hidden, partly as firms are often reluctant to share information about which academics they engage as consultants and for what purposes (Thursby & Thursby 2011).

Consulting offers greater financial rewards to academics than e.g. owning shares in a spinout company, licensing patents or writing books for profit (Bains 2005). Income from consulting fees may be paid to the university, but often it accrues to the individual researcher (D'Este and Perkmann 2011), and not all consulting activity is therefore visible to the university. Indeed, much consulting is not disclosed to the university (Abramovsky et al. 2004; Wright et al. 2008; Thursby et al. 2009). However, according to D'Este and Perkmann (2011, p. 331),

> ***[Consulting] allows academics … to build personal relationships with industry practitioners and learn about industry problems and applications.***

In a study of knowledge exchange in a group og European mid-range universities, Wright et al. (2008) found that consulting was often used in collaborations with local firms, as a flexible way of managing smaller scale research projects, though the majority of consulting agreements were entered into with large firms and government authorities.

For researchers from the social sciences and humanities (SSH), contract research and consulting are the most frequent mechanisms used for direct interaction with industry (Abreu & Grinevich 2013; Olmos-Peñuela et al. 2014). Presumably this has to do with the fact that establishing collaborative research ventures is more difficult in the SSH, in large part because firms and academics alike have less of a tradition for doing so. Contract research and consulting can thus provide a key door to industry, alongside collaboration on education, that can function in lieu of or lead to collaborative research (DEA 2014a).

Abreu & Grinevich (2013) moreover pointed out that academics' engagement with industry is different for SSH-researchers than for researchers from other scientific disciplines, relying more heavily, for instance, on dissemination of research via public lectures and books written for a non-scientific audience

For researchers from all disciplines, consulting can be an important source of ideas for new academic research paths and projects (Mansfield 1995).

Perkmann & Walsh (2008) pointed out that consulting can take various forms and serve several different ends. They defined academic consulting as "the provision of a service by academics to external organizations on commercial terms." Moreover, based on the motives for consulting and the nature of the relationship to the client firm, the authors distinguished between consulting, which is *opportunity-driven* (driven by the opportunity to earn personal income), *commercialization-driven* (with a view to technology development) and *research-driven* (related to the academic consultant's own research projects). Perkmann & Walsh (ibid.) called for future empirical research to investigate how and when in their career academics engage in different types of consulting activities.

INDUSTRY RESEARCH CENTERS, INCUBATORS AND SCIENCE PARKS

In an attempt to build stronger ties to industry and/or to support the establishment and survival of spinout firms, many universities have established incubators, science parks and industry research centers catering to both new and established science based firms.

The increasing importance of complex sets of specialized skills and large teams of researchers to solve scientific and technological problems and the search for ever more effective ways to bring public and private science together has led to the establishment of a growing number of *university-industry research centers* or UIRCs (Boardman & Gray 2010). These centers are often distinct physical units, typically located away from industrial laboratories.

Science parks provide workspace and meeting places for science based and innovative companies (Berbegal-Mirabent et al. 2015), both large and small and both new and incumbent. OECD (2013, p. 64) describes the role of science parks as "promoting the economic development and competitiveness of regions and cities by creating new business opportunities and adding value to mature companies; fostering entrepreneurship and incubating new innovative companies; generating knowledge-based jobs; building attractive spaces for the emerging knowledge workers; enhancing the synergy between universities and companies".

Meanwhile, *incubators* provide facilities and support for newly established firms and thus bring entrepreneurs together (Grimaldi & Grandi 2005). OECD (2013, p. 64) describe the function of business incubators as "accelerating the growth and success of entrepreneurial companies through an array of business support resources and services that could include physical space, capital, coaching, common services, and networking connections".

The first *science parks* were built in the 1950s in the US and in the late 1960s in Europe, and their numbers expanded rapidly in the 1980s and 1990s (Veugelers 2014). Incubators are often established in connection with, and even co-located with, science parks.

Being affiliated with an incubator may provide a new firm with benefits such as easier access to researchers, facilitated recruitment of graduates, access to good infrastructure, lower costs and other benefits of pooled and shared resources (Jensen & Thursby 2002; Chan & Lau 2005; Veugelers 2014). Mentoring and support from an incubator can be expected to positively impact both the number and performance of spinouts from an organization (Cooper 1984; Rothaermel & Thursby 2005; Veugelers 2014; Berbegal-Mirabent et al. 2015).
Research moreover shows that locating in a Science and Technology Park increases firms' likelihood of cooperation for innovation, and the intangible (Vásquez-Urriago et al. 2016).

Benefits are however not guaranteed (see e.g. Lasrado et al. 2016). Díez-Vial & Fernández-Olmos (2015) found that firms who have engaged in previous cooperation with universities and research institutions benefit most from being located in a science park, as they are better equipped to access and use of knowledge in the park.

Mian (1997) proposed that incubators should be assessed on three performance dimensions – program sustainability and growth; tenant firm's survival and growth; and contributions to the sponsoring university's mission – as well as the scope and effectiveness of the facility management policies, and the provision of services.

Overall, the success of science parks and incubators has been mixed (Cervantes, 1998; Mowery, 1998), and the evidence on their impact is inconclusive (see e.g. Kochenkova et al. 2015; Lamperti et al. 2015; Liberati et al. 2015).

For example, using Italian survey data, Liberati et al. (2015) found that while firms located in a science and technology park tended to exhibit better performance than other comparable firms, there was no evidence that *entering* a science and technology park improved firms' business performance or their propensity to innovate. Similar findings were found, also for Italian data, by Lamperti et al. (2015).

Science parks and incubators have also been criticized for low exit rates (Vohora et al. 2004; Phan et al. 2005), suggesting a need to help tenant firms develop to the point of exit (Kochenkova et al. 2015).

On a related note, Schwartz (2009) examined that happens to 352 German business incubator firms *after* leaving the incubator facilities. The results showed that "graduation" from the incubator is followed by an immediate *negative* effect on survivability for up to 3 years after leaving the incubator. Moreover, firm performance during the incubation period was found to be an indicator of the likelihood of post-graduation survival.

Based on a study of Italian firms located in a technology incubator within a science park, Colombo & Delmastro (2002) confirmed prior findings of marginal differences in input and output measures of innovative activity for on- and off-incubator firms. They also found, however, that the science parks attracted entrepreneurs with better human capital (as measured by their education and prior working experience), and that incubator firms showed better performance as measured by growth rates, adoption of advanced technologies, aptitude to participating in international R&D programs, access to public subsidies and establishment of collaborative arrangements, particularly with universities. Lastly, they find it easier to get access to public subsidies. The authors argue that these findings underline the importance of science parks for the development of newly established technology-based firms, particularly in countries that, like Italy, are characterized by relatively weak innovation systems. But how much of the superior performance incubator firms demonstrated in some studies can be attributed to the contribution of the incubator? Direction of causality can run several ways. For example, Lindelöf & Löfsten (2002) pointed out that it is not surprising that firms in science parks have higher R&D intensity in view of the importance of R&D for starting new firms.

There are many different types of incubators and science parks, meaning that it's difficult to compare performance across them. (Aernoudt 2004). Incubators may for example be for-profit, non-profit or university-based incubators (Peters et al. 2004), and they may be sector-specialized or generic in nature (Schwartz & Hornych 2008). Some of the possible benefits of a sector-specialized approach are high-quality premises and equipment, improved (i.e. more targeted) service and consultancy offerings, and image effects of the location (Schwartz & Hornych 2008).

Bergek & Norman (2008) pointed out the heterogeneity in approaches used in incubators. Among other things, the authors distinguished between "idea-focused" and "entrepreneur-focused" selection of firms as well as between "picking-the-winners" and "survival-of-the-fittest" selection.[25] Another key activity for incubators is providing business support, which Bergek & Norman describe as a continuum from "laissez-faire" approaches to "strong intervention". Finally, they underline that incubators tend to focus on different types of innovation systems – technological, regional or cluster – which in turn influences their strategies. The age of the incubator may also matter for their impact:

[25] On a related note, Aerts et al. (2007) found that incubators tend to screen and select new entrants either based on an assessment of the market for the tenant's product offering or of the characteristics of the tenant's management team. However, the authors' found that the tenant survival rate is positively related to a more balanced screening profile, which takes both the potential market and the management team into account.

Bruneel et al. (2012) found that all incubators offer similar support services, but tenants in older incubators are less likely to make use of this portfolio of services. The authors suggested this might be the result of slack selection criteria and the absence of clearly defined exit policies for firms in the incubator, and suggested that older incubators should update their service offering while imposing stricter selection criteria and exit policies.

INFORMAL MECHANISMS FOR COLLABORATION

University researchers and industry can also engage via non-commercial mechanisms, i.e. where no money is exchanged. This includes participating in meetings, seminars, conferences and the like, and advice and favors solicited informally via personal ties.
Such informal ties can complement other mechanisms for knowledge exchange. For example, based on data gathered from the Madrid Science Park, Díez-Vial & Montoro-Sánchez (2015) stressed the importance of long-term relationships with universities, based on both formal and informal mechanisms, to access technical knowledge from the universities.

Moreover, Ponomariov & Boardman (2008) found that university scientists' informal interactions with private firms increase both the likelihood and intensity of collaborative research with industry.

A handful of studies have delved into the job mobility of researchers from academia to industry and vice versa as another vital mechanism for knowledge and technology transfer. Academic researchers may venture into the private sector in connection with the foundation of a university spinout (see chapter 7) or to move to an established firm. Meanwhile, many firms may be interested in hiring scientific staff to access their expertise and/or strengthen in-house absorptive capacity (Zucker et al. 2002b; Edler et al. 2011). Mobility among researchers may take the form of either permanent or temporary shifts.

Schartinger et al. (2002) showed that personnel mobility is intensively used as a means of transferring know-how from academia to industry. Job mobility from academia to industry is however particularly common in fields such as engineering, information technology or biotechnology (Martinelli 2001).

Researchers' mobility can be an important mechanism for knowledge exchange between academia and industry as intersectoral changes in jobs can provide researchers with access to new networks and scientific and technical human capital, effectively contributing to or strengthening knowledge spillovers (Meyer-Krahmer & Schmoch 1998; Zellner 2003; Dietz & Bozeman 2005; Wright et al. 2008; Edler et al. 2011). Mobility from academia to industry is particularly critical when there is need to transfer knowledge which is hard to codify and embodied in researchers or students at the university (Fritsch & Krabel 2012; Veugelers 2014). For example, a study based on empirical data obtained from scientists formerly employed by the Max Planck Society in Germany found that this transfer primarily consists of elements of knowledge that underlie complex problem-solving strategies in basic research (Zellner 2003).

Other studies have highlighted the role of academics' mobility not just for transferring research knowledge but also information about potential collaboration opportunities and possible collaboration partners in academia. In fact, an unpublished study (Markus 2016) examines the influence of Danish scientists' mobility from academia into private firms on firms' propensity to engage in R&D collaboration with universities. Scientists are however defined very broadly in this study to include both M.Sc. and

Ph.D. graduates in engineering, natural, veterinary, agricultural or health sciences. Nonetheless, as would be expected, the study supports the hypothesis that recruiting academic researchers, both young and established, increases firms' likelihood of engaging in collaboration with universities, particularly when the firm's in-house scientist ratio is lower.

There are also indications that this is chiefly a one-way mechanism: industry experience is not recognized in academic job applications and most researchers, who have worked in the private sector, face large difficulties returning to academia at a later stage in their careers (Wright et al. 2008).

Indeed, Wright (2014, p. 329) argued that

> ***It is by no means clear that such moves will be beneficial to academics' career development if the emphasis in promotion and tenure decisions on publications continues to be disconnected from policy pressures to become more business engaged. Academics seconded to industry may find it hard to find a way back unless they can continue to publish while working for industry. These observations suggest a need for more fine-grained and less contradictory policy towards academic mobility that allows for multiple performance measures.***

Unfortunately, such mobility has been the subject of very little systematic analysis; the role of such mobility as a mechanism for knowledge transfer has only more recently been acknowledged, and limited data is currently available (Wright et al. 2008).

INTERDEPENDENCE BETWEEN COLLABORATION MECHANISMS

Landry et al. (2010) acknowledged that while the literature tends to treat various mechanisms for collaboration and commercialization as distinct, in practice these mechanisms constitute a portfolio of activities that academics can draw upon. Some of these mechanisms may complement or substitute for each other, while others may be entirely independent of.

Using data on Canadian researchers, the authors found evidence of three distinct "portfolios" of knowledge and technology transfer activities: A first portfolio comprises scientific publications, patenting, spinout creation, consulting and information knowledge transfer; these activities were found to be complementary, i.e. interdependent activities that can reinforce each other. A second portfolio included teaching activities and scientific publications, which were substitutes for each other. Finally, a third portfolio included teaching activities and other activities independent from teaching (patenting, spinout creation), consulting and informal knowledge transfer.

Abreu & Grinevich (2013, p. 410-411) echoed Landry and colleagues' point about the existence of interdependencies between different mechanisms for collaboration, and presented an example

> ***… from a respondent who is head of department in the field of maritime engineering. The respondent emphasises the importance of the interactions between consultancy work, research funding and student recruitment. His research group has achieved excellent research outcomes, and also actively engages in consultancy work for the maritime industry (such as risk assessment), runs bespoke courses for business and industry, and has obtained a significant number of research grants over the past ten years.***
>
> ***These activities all complement one another, and reinforce the reputation and research profile of the group. The activities are entrepreneurial in the sense that they involve the identification of opportunities to introduce new***

products and services, involve an element of risk in terms of costs and research time, bring financial rewards to the academics involved, contribute to the prestige of the department and institution, lead to the recruitment of research staff and students and, indirectly, lead to further financial rewards in the form of research funding.

However, Van Looy et al. (2011) found no evidence of trade-offs between knowledge/technology transfer mechanisms; instead, they found that contract research and spinouts activities tend to facilitate each other.

Generally speaking, some mechanisms for collaboration may be more likely to be combined than others. For example, Ding & Choi (2011) found evidence that founding and advising companies are two divergent paths for commercially oriented university scientists. They examined the commercial activities of 6,138 university life scientists and found that scientists who become academic entrepreneurs had different profiles than those who become scientific advisors to established firms. For instance, founding activity occurred earlier during a scientist's career than advising. Founding and advising scientists also differed on other factors such as gender, their research productivity, social networks and employer characteristics.

CAN / SHOULD WE MEASURE ALL FORMS OF COLLABORATION?

Much of the interaction described in this chapter occurs “under the radar”, so to speak. For example, Link et al. (2007) point out that many instances of interaction between academics and firms are not disclosed to the university TTO; they are moreover subject to low IPR protection and obligations are “normative rather than legal” in nature (Link et al. 2007, p. 642).

Increasing recognition of the volume and importance of various formal and informal mechanisms for interaction has created interest in documenting this interaction and the value that it creates. For example, Mars & Rios-Aguilar (2010) argue that more attention should be paid to the intangible value created by academics who engage with the commercial world, e.g. for student learning.

On a similar note, Fini et al. (2010) argued that many years’ narrow focus among policymakers on patenting, licensing and spinout formation as key vessels for creating value from academic research has similarly narrowed and skewed the focus in university TTOs. As a consequence, they may fail to properly support other mechanisms, that are potentially more valuable to society and even to the university (Fini et al. 2010). For example, entering into a collaborative project may provide the university with private funding for research which exceeds any income that could have been made through the sale or licensing of a patent (DEA 2013a).

Another possible detrimental effect of the policy-level focus on patenting and spinouts may be that decision makers withdraw funding from fields or activities that are less visible or seen to have little direct economic impact (Abreu & Grinevich 2013). Fortunately, however, many TTOs in Denmark (DEA 2013), and presumably also around the world, are working on developing a broader approach to their work, helping projects find the best possible route to commercialization, regardless of whether or not that involves a patent or the establishment of a new company.

Nonetheless, it is important to consider how measurement systems impact incentives and behavior in universities. For example, Langford et al. (2006) analyzed efforts by the Canadian Government to encourage and measure commercialization of university knowledge. They concluded that current indicators (or proxies) focus on licensing and spin-off and fail to measure other, important mechanisms for knowledge exchange, and that the most readily available proxies are based on aggregate data and inadequate in providing an accurate picture of innovation processes. Finally, they caution against “proxies becoming goals”, that is, that indicators become de facto objectives for universities (as for firms and government), thus potentially leading universities and industry to engage in counterproductive activities.

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