Contribution of academic research to innovation and growth[1]

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1. Introduction

To what extent does publicly financed academic research[2] contribute to economic growth? Does publicly funded academic research complement or substitute private investment in research and development (R&D)? These are important questions in relation to political choices to fund academic research.

To answer these questions, we need to understand how the knowledge created by publicly funded research spills over to the rest of the economy. Does academic knowledge transfer mainly through direct contact between universities and firms, or through the mobility of students and researchers recruited by private firms?

This report seeks to answer these questions. Universities furnish two valuable assets to society: skills and new ideas. First, universities perform basic scientific research, creating new knowledge and providing scientific capital. Second, universities disseminate this new knowledge and create human capital through their teaching. What are the effects of these two inputs to society?

To answer these questions, we first review the economic literature on the contribution of publicly funded academic research to innovation, productivity and growth. We then present descriptive statistics for Denmark in relation to these questions.

Effects of academic research can come in many forms. The effects can, for example, be in the form of higher productivity and growth because firms/industries/countries, including the public sector,

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[2] Unless stated otherwise, "academic research" will refer, throughout the report, to publicly-financed research performed by universities.

produce products and services of higher quality per unit of input used in production as a consequence of private R&D and innovation activities founded on academic research. Moreover, the effects can be in the form of improved health conditions, reduced crime, and improved citizenship among others. In this report we focus on the effect of academic research measured by economic value added, i.e., gross domestic product (GDP) for countries, industrial value added for industries, and firm sales or firm value added for firms. We use this limitation because the addressed topic is the effect of academic research on output and growth in the private sector.

The literature shows that academic research affects productivity and corporate R&D. The main conclusions are that (i) spillovers from academic research to the rest of the economy do exist, (ii) the diffusion of academic research to the rest of the economy occurs with long lags, (iii) academic research complements private R&D, rather than crowing it out, (iv) the overall value of academic research to society is large, but estimates vary due to the difficulty of calculating social rates of return, and (v) there are multiple pathways through which academic research affects society and that link is not always direct, nor obvious.

Focusing on research-based education, we also review the findings on the provision of university graduates, who take with them the knowledge resulting from their education, to innovation and growth. Our survey shows that the contribution of human capital to productivity growth depends on both its composition (skilled vs unskilled labor) and the distance to the technological frontier. Sectors and regions close to the technological frontier benefit most from increases in research-based education spending. Additionally, research-based education spurs private sector innovation and economic growth.

There are multiple pathways through which spillovers from academic research may occur. Since some channels are more easily measured than others, we only review the evidence for a limited number of topics. Academic patenting and licensing have received a lot of attention as potential tools to transfer knowledge from academia to the private sector. But while academic patenting and licensing have been growing over time, this phenomenon is highly concentrated in few universities and a limited number of industries. Survey evidence shows that academic patents and licenses are among the least effective mechanisms to promote private sector innovations. Instead, informal contacts with faculties and recruitment of university graduates are the biggest contributors to corporate innovation.

After reviewing the literature, we present descriptive statistics for Denmark. Specifically, we describe five aspects related to academic research. First, we present an overview of R&D activities in Denmark and investigate the distribution of R&D expenditure across industries and firms. The literature survey shows that university research and private R&D are complementary inputs in the production of knowledge and the impact of university research is higher in R&D-intensive industries and firms. We show that private R&D expenditures are highly concentrated in relatively few firms within a narrow set of high tech industries.

Second, we study a potential mechanism through which university research can transfer to the private sector directly, namely the extent of cooperation between universities and private firms. This aspect is limited by the lack of available data. However, we do find that the 5 year growth rate of labor-productivity is higher in firms that cooperate with Danish universities.

Third, university graduates are an important output from universities. These graduates may potentially play an important role for the production of knowledge in firms in comparison to graduates from non-university higher education institutions. To investigate the role of university graduates in Danish firms, we present descriptive statistics of university educated employment from the eight Danish universities. We show that firms with innovation activities are more intensive employers of university educated people than firms with no innovation activities. Moreover, we find that firms with R&D activities employ more university educated people than firms with innovation activities but no R&D.

Fourth, we provide descriptive statistics for the growth of labor productivity in firms with varying shares of university trained workers, to investigate if research-based education correlates with productivity growth. We find that the 5 year growth rate of labor-productivity is higher in university education-intensive firms compared to non-university education-intensive firms, independently of the innovation status of the firm. The labor productivity growth differential is, however, larger for innovating firms, especially those carrying out formal R&D.

Fifth, we investigate the contribution of university graduates to size of innovation (incremental or drastic).We find that firms doing R&D and firms employing higher shares of university graduates have higher size of innovation.

Based on the literature review and the descriptive statistics we propose two potential studies. First, the descriptive statistics show that university educated employees may play an important role for innovation and growth. However, it is not clear whether there is a causal effect going from higher university education intensity to productivity growth or whether the mechanism works through knowledge production, i.e., innovation and R&D. Another important aspect that is not clear-cut is whether university education creates specific qualifications that are particular useful in knowledge production or whether university education contributes through more years of education. Second, evidence of the contribution of the respective channels of industry-science linkages, as well as the evaluation of public policies aiming at strengthening these linkages are limited, particularly in the Danish context. The current stage of research in this area is still far from being able to assess whether such policies, if any, can effectively stimulate the contribution of universities to innovation and productivity.

The report is organized as follows. Section 2 discusses why governments should invest in academic research. Section 3 presents the literature review. Section 4 presents the analysis for Denmark based on descriptive statistics. Section 5 suggests two potential projects studying the contribution of academic research on innovation and growth.

2. Why should governments invest in academic research?

In this report, we will present a review of the literature on the contribution of academic research to innovation and growth. Specifically, the focus will be on answering the following questions: How does publicly financed academic research contribute to overall economic growth? What is the return to academic research? Are publicly financed research and private research and development (R&D) complements or substitutes? And through which mechanisms are knowledge transferred from universities to the private sector. Before we turn to answering these questions in Section 3, we describe the societal importance of publicly financed academic research.

2.1. The societal impact of academic research

A 2015 report from the Massachusetts Institute of Technology (MIT 2015) lists the four biggest scientific achievements of the year 2014: the first spacecraft landing on a comet, the discovery of a new fundamental particle (the Higgs boson), the development of the world's fastest supercomputer, and new research in plant biology. These developments all have important implications but the path from basic science to the findings spanned several decades.

Public funding of academic research is debated, because it often seems to have no immediate payoff. However, the economic payoff to society can be quite large compared to the amount invested, because a fundamental advance in knowledge can serve as an input for applied research. Pure basic research conducted in universities is sometimes driven by epistemic motives and the economic payoffs will come about much later. As Mokyr (2005) notes, Niels Bohr did not think about the development of MRIs or laser technology while working on quantum physics.

Mazzucato (2015) provides a number of case-studies on the importance of research that was publicly financed, prior to involvement by the private sector. For example, the technologies that make smartphones “smart” – the internet, GPS, touchscreen, Siri – were all publicly funded.

The benefits of academic research go beyond the traditional STEM fields. Insights from social science research can aid policy makers in their decisions, save government money and improve opportunities for economic growth. The ultimate output of social science research is information, rather than new products. This new information can be the basis of welfare-enhancing changes for households, firms and governments.

Social sciences can help understand the causes of long-run economic growth and the role of public policy in stimulating growth. For example, the design of spectrum auctions, used by governments to license the right to use specific signals, raised important sums of money and was guided by research in game theory, a branch of economics.[3] Research from Denmark shows that automatic enrollment in a pension savings plan is a more effective way to get people to save money and has a lower fiscal cost than offering them tax incentives (Chetty et al. 2014).

2.2. Academic research as a "public good"

The modern analysis of the production and distribution of basic scientific knowledge can be traced back to the analytical work of Nelson (1959) and Arrow (1962)[4] who study the implications of the difficulties of privately appropriating the economic value of academic research findings. Discoveries arising from academic research are close to the economic concept of a "public good": they have the possibility to be used in a variety of non-competing applications (they are "**non-rival**") and they are made available through publication in scientific journals so everybody can access them (they are "**non-excludable**").

Consequently, individuals or firms cannot be effectively excluded from using the output of academic research and when used by one individual or firm the availability to others is not reduced. This characteristic implies that the private incentive to invest in academic research is too small to secure the level of investments that is desirable from a societal point of view: the inventor will bear the full cost of the research, but will only get a small fraction of the return, making his willingness to invest too small from a societal point of view. In more technical terms, we say that the social returns to research is higher than the private return: the private inventor only internalizes the value from the research that accrues to him, whereas the value to society is the value generated by all firms and individuals that benefit from the knowledge created by the private inventor.

Arrow (1962) first articulated the need for public funding of basic research, arguing that the public good nature of basic research results in a systematic "**market failure**" which, in the absence of remedial actions in the form of public funding, would result in societal underinvestment in science. Because of the divergence between the private and social returns to basic research outlays, without

[3] http://www.ens.dk/en/Telecom-and-Spectrum/Spectrum/Auction-and-Public-Tender-Licences/800-MHz-Auction

[4] Both Nelson and Arrow's argument relates to the broader concept of "basic research" and therefore also applies to corporations. However, as Arrow notes, the bulk of basic research is carried on by universities.

public funding, investment in basic research would be suboptimal and its direction would be biased towards more applied, close to market outcomes.[5]

Dasgupta & David (1994) elaborate on Arrow's contention, arguing that because research that is disclosed is far more socially valuable than research held secret, basic research should be made available for unrestricted use. The disclosure of basic science is achieved through the contractual provisions of research funding, and through the norms and incentives for openness found in public research institutions. Only publicly funded scientists can ensure the broad disclosure of research findings that leads to long-term growth (Romer 1990).

The flip side of basic research being a "public good" is that obstacles for the non-excludability and non-rivalry characteristics will make basic research less valuable. Failure of non-excludability for example generated by government policies or failure of non-rivalry for example because knowledge diffusion is imperfect can thus limit the social value of basic research.

2.3. Pathways from public research to productivity and growth

We will show in this report that there is a positive relationship between publicly funded academic research, productivity and growth. However, the path from basic science to growth is not direct, mechanical or obvious. The impact of university research can span decades, traverse disciplinary boundaries and wander back and forth between academia and industry.

Moreover, the effect of academic research will depend on complementary policies such as the definition of intellectual property rights for publicly funded research (that may hamper the diffusion of scientific knowledge) or R&D subsidies that favor incumbent firms, rather than innovative entrants.

The relationship between market structure, market dynamics, R&D and innovation is going to determine how scientific knowledge will be absorbed and diffuse in the economy. In that respect, it is important to design policies and secure conditions that will provide the right incentives for firms and industries to perform R&D and innovate. Innovation-led growth is generally associated with high turnover rates attributed to the principle of "creative destruction", a process whereby new technologies and new products make old ones obsolete, forcing existing companies to quickly adapt

[5] In a context of private R&D, Jones & Williams (1998) investigate whether there is too much or too little R&D. The authors find that optimal R&D investment from a societal point of view is at least two to four times actual investment.

or to exit. The success of this reallocation process hinges on the existence of institutions and policies favorable to that dynamic. For example, industrial policies subsidizing incumbents reduce economic growth because they encourage the survival and expansion of these firms at the expense of potential highly innovative entrants (Acemoglu et al. 2013). The implications of such policies are important because the evidence for Denmark attributes over 50% of productivity growth to this reallocation process (Lentz and Mortensen 2008).

Universities have two main missions; the first mission is to extend the stock of knowledge through academic research and the second mission is to disseminate this knowledge through the provision of research-based education. From these two missions, there are a number of pathways through which academic research affects productivity and growth (see Salter & Martin, 2001; Martin & Tang, 2007; Valero & Van Reenen, 2016; Veugelers & Del Rey, 2014).

First, universities are producers of human capital and educational attainment is linked to individual productivity. Human capital is not only affected by the quantity, but also by the quality of inputs provided by schooling. In this perspective, research-based education plays a distinctive role: university trained graduates bring with them knowledge of frontier research but also an ability to solve complex problems, perform research, develop ideas, and participate in innovation activities (Salter and Martin 2001).

Second, basic science expands the stock of knowledge. The payoffs entrained by contributions to fundamental knowledge may come quickly, but more often are not realized for a long time.[6] The economic value of advances in basic science is therefore difficult to forecast, or even to gauge in retrospect.

Third, universities affect growth through innovations. This effect may be direct as university researchers themselves produce innovations, or indirect through collaborations between university scientists and private businesses.

Fourth, basic science may affect growth through changes in the industrial organization of an industry. Research universities and "star" academic scientists were crucial in the creation of biotechnology start-ups, providing a source of Schumpeterian clustering around a technology that

[6] Stokes (1997) exemplifies "pure basic research" by the work of Niels Bohr, where the research is driven by purely epistemic motives and the economic payoffs will come about much later, and "use-inspired basic research", with immediate applications, by the work of Louis Pasteur

was heavily dependent on the underlying publicly-financed science (Zucker, Darby, and Brewer 1998).

Finally, universities can contribute to the provision of social knowledge which may matter for growth. Universities can promote strong institutions directly by providing a platform for democratic dialogue and sharing of ideas, through events, publications, or reports to policy makers (Valero and Van Reenen 2016), allowing firms, governments and citizens to make informed decisions.

Effects of academic research can come in many forms. The effects can, for example, be in the form of higher productivity and growth because firms/industries/countries produce products and services of higher quality per unit of input used in production as a consequence of private R&D and innovation activities founded on academic research.

Moreover, the effects can be in the form of improved health conditions – resulting in better quality of life and longer life expectancy – reduced crime, improved citizenship among others. In the review presented in Section 4 below, the main focus is on the effect of academic research measured by economic value added, i.e., gross domestic product (GDP) for countries, industrial value added for industries, and firm sales or firm value added for firms. We use this limitation because our main focus is the effect of academic research on output and growth in the private sector.

Before presenting the literature review, we discuss two aspects in greater detail. Box 1 defines the social return to academic research and box 2 discusses the theory of endogenous growth that provides a useful framework to thinking about the research, innovation and growth–nexus.

Box 1: Spillovers and social returns to academic research

To compute the social rate of return from investments in academic research, the value to society, we have to compare the stream of benefits of that investment with what would happen if the funding to academic research were withdrawn, holding constant investments in non-academic activities (Mansfield 1991). Without the investment in basic science, the findings of that research would not be available, potentially preventing or delaying productivity gains to the rest of the economy. The social benefits of academic research are difficult to estimate as we would have to be able to trace and monetize all the knowledge flows from universities to the rest of the economy.

Knowledge flows from academic research to other sectors of the economy can be divided in two broad categories. Knowledge spillovers, positive externalities from university research to firms, and market-mediated channels that involve a contractual relationship between universities and firms.

"Spillovers" capture the idea that some of the economic benefits of research activities accrue to economic agents other than the party that undertakes the research. Informal contacts, personnel mobility (scientists or students) and industry-science networks are ways of exchanging knowledge between enterprises and public research, which increase the firms' productivity. These spillovers are created by a combination of the new knowledge resulting from basic research efforts, and the commercialization of the new technology in terms of a product or process that is successfully implemented in the marketplace. Griliches (1995) identifies two forms of spillover, geographical spillovers and spillovers across sectors and industries. Given the potential lag between basic research and its economic impact, (Mokyr 2005) emphasizes the importance of intertemporal spillovers.

On the other hand, collaborative agreements, R&D contracting, academic patenting and licensing, academic or student spin-off creation or firms' investment in absorptive capacity (their ability to recognize, assimilate and exploit new knowledge) by hiring university-trained employees, all involve formal relationships between universities and businesses.

In practice, it is difficult to disentangle knowledge transfers governed by market transactions from uncompensated knowledge flows. Studies of knowledge spillovers are often unable to observe market-based relationships between universities and firms. Conversely, studies of market channels between academic scientists and firms do not account for spillovers surrounding the market transaction (Mowery and Ziedonis 2015).

Box 2: Endogenous Growth theory

The theory of endogenous growth provides a theoretical framework to understand the relationship between education, research and development (R&D) and economic growth (Romer, 1990; Aghion & Howitt, 1992; Grossman & Helpman, 1991).

These models show that a country's rate of economic growth depends on technological progress, or improvements in the technology that transforms factors of production into output. That technology, called Total Factor Productivity (TFP), is measured as the portion of output not explained by the amount of inputs used in production. As such, it is determined by how efficiently inputs are used in production.

Improvements in TFP arise from process and product innovations which come about from intentional investments in R&D/private market-driven R&D. This investment is fundamentally guided by the underlying invention of people, which flows from the knowledge and skills of the population.

Education plays a crucial role in increasing the innovative capacity of a country by producing a continuing stream of new ideas and technologies. Education can therefore spur long-run economic growth by (i) increasing aggregate productivity through accumulated human capital (ii) generating and diffusing innovations and (iii) improvements in the quality of human capital.

Acemoglu, Zilibotti, and Aghion (2006) describe how the "technology frontier" affects the type of innovation pursued by a country or a firm. When that country or that firm is distant from the technology frontier, climbing up the quality ladder through product or process innovations requires an investment in "imitation" or "adoption" activities. A firm lagging behind the technology frontier has to identify which product or production process is more productive or profitable which requires knowledge and human capital.

Innovation close to the technology frontier is different because it requires skills and investment in research activities that are more difficult, costly, and yield more uncertain outcomes. The type of human capital required to pursue frontier pushing research is therefore different. Frontier-pushing innovators come from or are closely linked to fundamental research in universities and their productivity in the invention process will depend on the quality of their education.

Vandenbussche, Aghion, & Meghir (2006) propose a model that captures these features and where technological progress results from a combination of innovation and imitation. Under the assumption that innovation is more skill-intensive than imitation, they show that investing in high-skill human capital enhances productivity growth all the more the economy is closer to the world technological frontier.

3. Literature review

3.1. Macro and industry-level evidence

In this Section we will review the empirical literature that studies the impact of universities on aggregate outcomes in two ways. First we will explore the aggregate evidence linking academic research, productivity and corporate R&D. Second, we will survey the aggregate evidence of the relationship between research-based education, innovation and economic growth.

3.1.1. Effect of academic research on productivity and corporate R&D

In this Section we will review the research investigating the existence of spillovers from government funding of academic research to aggregate outcomes in the private sector. While most studies do not identify the pathways of these spillovers, they start with the premise that academic research augments the productivity of firms by expanding the pool of knowledge available to the economy. Although the social rates of return to investments in academic research are difficult to calculate, some studies attempt to give an estimate. The literature shows that (i) spillovers from academic research to the rest of the economy do exist, (ii) the diffusion of academic research to the rest of the economy occurs with long lags, (iii) academic research complements private R&D, rather than crowing it out, and (iv) the overall economic value to society is large, but estimates vary due to the difficulty of calculating social rate of returns.

Guellec & Van Pottelsberghe de la Potterie (2004) provide the most comprehensive analysis of the impact of R&D on TFP (growth) at the macro level. They distinguish between R&D performed in the public sector and corporate R&D in 15 OECD countries (including Denmark) from 1980 through 1998. Public R&D stock, which includes higher education and government R&D expenditures, has an elasticity of 0.17 compared to 0.13 for corporate R&D. The authors interpret this result as a sign that publicly funded research is more basic in nature and generates a higher degree of spillovers to the rest of the economy. They also show that the elasticity of TFP with respect to public R&D is higher when corporate R&D intensity is higher. This suggests that without sufficient absorptive capacity in the corporate sector, the ability of private firms to take advantage of technological opportunities from public research will be limited.

Guellec & Van Pottelsberghe de la Potterie (2004) further show that the impact of public sector R&D on TFP growth is positively affected by the proportion accounted for by university R&D but not by other public research institutes. The authors explain this finding by the fact that government (non-university) R&D is more targeted towards strategic areas (e.g. public health, environment, defense), and is therefore less likely to directly impact TFP growth. Finally, the authors find that these impacts become statistically significant within three years. These time lags are short compared to the findings from the micro literature that we will review later.

While Guellec and Van Pottelsberghe de la Potterie summarize investment in basic science in a monetary sense, Adams (1990) constructs a series of 19 industry-specific stocks of scientific knowledge based on the count of articles in a number of academic journals. This approach allows him to assess the contribution of basic science to industry, using article counts as a measure of scientific input. Publications are field-specific and weighted by the number of scientists within a field, working within an industry, so that the author can characterize not only the stock of knowledge available to that industry, but also the potential to make use of it. Adams (1990) uses these stocks of publications to explain TFP growth in 19 manufacturing industries from 1953 to 1980 and finds that publications stocks positively affect TFP growth with a lag of 20 years in their own industries and 30 years for knowledge that spills over to other industries.

In a related study, Jaffe (1989) uses variations across US states in corporate and university R&D to assess the contribution of university-based R&D to corporate patenting across states in five industrial fields (chemicals, drugs and medicine, electronics and electrical, mechanical arts, and others). Jaffe shows that there are spillovers from university research to industrial patenting (with an elasticity of about 0.6) and that university research stimulates industrial R&D, but not vice versa.

Toole (2007) explores the interplay between private R&D investment in the US bio-medical industry, and publicly funded basic and clinical research performed in public and private not-for-profit institutes and universities. The author separates both public and private R&D investment expenditures into seven medical therapeutic classes. Public and private R&D investment data are then matched by technology class over the period 1981-1997 to construct a panel data set. Toole finds that public academic research stimulates additional private pharmaceutical R&D investment after a lag.

However, pharmaceutical R&D investment responds differently to each type of public research. The response of pharmaceutical R&D investment to academic research, which is characterized by a high degree of uncertainty in its scientific maturity and its potential market applicability, follows a Ushape. Firms respond quickly to new information from public academic research and after a period of holding the level of investment constant, to allow scientific and market uncertainties to resolve, firms again increase private R&D investment. Toole concludes that the long-term-elasticity (within eight years) of private R&D investment with respect to public funding is 1.69.

On the other hand, public clinical research has very little scientific or market uncertainty, and the industry's R&D response to public clinical research is shorter in duration and smaller in magnitude with an elasticity of 0.40. The results show that firms increase private R&D investment in response to public clinical research within the first three years.

In a follow-up study, Toole (2012) finds that a 1% increase in the stock of public academic research is associated with a 1.8% increase in the number of industry new molecular entity applications after a substantial lag of 17 to 24 years. Toole estimates the total direct return to public academic research to be 43%.

Valero and Van Reenen (2016) compile data detailing the location of 15,000 universities in 1,500 regions across 78 countries over the period 1950 to 2010. They find that, universities do not only increase GDP in their own region but also in neighboring regions, creating a growth multiplier. The authors estimate that doubling the universities in one region increases that region's income by four per cent and country-wide income by 0.5 per cent. They also find that research oriented universities in technologically advanced economies have a stronger growth enhancing effect.

Valero and Van Reenen (2016) test several potential mechanisms explaining the link between university presence in a region and growth. They find that the growth effect of universities is related to (i) increases in the supply of skilled graduates who raise productivity in the firms they join and (ii) increases in innovation (as measured by an increase in patenting).

3.1.2. Research-based education, innovation and growth

Empirical research shows that education is an important determinant of economic growth in the long run. Education raises aggregate productivity not only through the private returns to greater human capital, but also through a variety of externalities such as technological innovation, increased work satisfaction, improved health decisions, reduced crime, improved citizenship, and better parenting (see the review by Woessmann, 2016).

In this Section, we will focus on the effects of research-based education. One important function of academic scientists is the provision of trained graduates, who go on to work in applied activities and take with them the knowledge resulting from their education. The macro literature shows that the contribution of human capital to productivity growth depends on both its composition (skilled vs unskilled labor) and the distance to the technological frontier.

Vandenbussche, Aghion, and Meghir (2006) provide evidence that education has heterogeneous effects on growth in a panel of 19 OECD countries in the period 1960-2000. They distinguish between primary/secondary versus tertiary educational attainment. They show that the growth-enhancing margin is that of skilled human capital rather than that of total human capital. Second, they show that skilled human capital has a stronger growth-enhancing effect in economies which are closer to the technological frontier. Assuming that innovation makes a relatively more intensive use of skilled labor, they interpret this result as a sign that the growth-enhancing effect of skilled human capital occurs through technological progress.

Aghion et al. (2009) examine the impact of public funding of different types of education on GDP growth across US states. Here we will focus on the results pertaining to research-based education. The authors show that states that are close to and far from the technological frontier experience different growth effects of research-based education spending. In a state close to the frontier, a thousand dollars of research-based education spending per person in a cohort raises growth by 0.04 percentage points. On the other hand, in a state far from the technological frontier, a thousand dollars of research-based education spending per person in a cohort decreases GDP growth by 0.07 percentage points, suggesting that the additional funding either induces out-of-state migration (to states close to the frontier) or crowds out more productive expenditures.

The authors show that innovation is an important channel for growth-effect of research-based education. Moreover, they show that funding of research universities and four-year colleges impacts innovation in the private sector. In a state close to the technological frontier, a thousand dollars increase in research-based education spending per student in a cohort raises patents per person by 6 per 100,000. But, in a state far from the technological frontier, an exogenous thousand dollar increase in funding of any type of higher education has no discernable effect on patenting.

Mohnen and Röller (2005) provide industry-level evidence for the idea that human capital is crucial for innovation. They identify skilled personnel as the single most important obstacle to innovation in a wide range of industries and countries.

3.2. Micro evidence

3.2.1. Effect of academic research on corporate outcomes

The micro literature confirms the findings of the aggregate evidence. There are knowledge spillovers from academic research to other parts of the economy. The literature uses data from firm surveys or patents (a surrogate for innovation) to quantify the contribution of basic science to firm-level outcomes.

Mansfield (1991) measures the benefits of academic research using the results of a survey of 76 US firms that have carried out commercial innovations in seven industries. Using estimates obtained from the firms about the importance of recent academic research (within 15 years of the innovation under consideration), Mansfield produces estimates of the private returns from academic research.

The study uses estimates from company R&D managers about what proportion of the firm's products and processes could not have been developed without the academic research. He finds that about ten percent of the product and process innovations of these firms could not have been developed without a substantial delay in the absence of academic research. Using these results, Mansfield estimates the social rate of return from academic research to be in the 20-30 percentage range. As he is careful to point out, this estimate is a lower bound as it ignores the social benefits from other innovations based on the same academic research, those accruing to consumers, those accruing outside the US and spillovers to firms in and outside the industry in question.

Mansfield (1998) reports the results of a follow-up study where he shows that academic research has become increasingly important for industrial research. In this second survey of 70 firms, Mansfield estimates that 15% of new products and 11% of new processes (accounting for 5% of total firm sales) could not have been developed without a substantial delay in the absence of academic research. Mansfield's second study also suggests that the time delay from academic research to industrial practice has shortened from seven to six years. While Mansfield does not estimate a rate of return to academic research, he suggests that increasing links between academic research and commercial activities may be resulting from a shift toward more applied and short-term academic research and of growing efforts by universities to work more closely with industry.

Beise and Stahl (1999) replicate Mansfield's survey using a sample of 2300 German manufacturing firms. They confirm Mansfield's findings, although they report a smaller impact of academic research on corporate innovation. They also show that academic research has a greater impact on new products than new processes, and that small firms are less likely than large firms to draw knowledge from universities. Other empirical evidence from firm surveys (Cohen, Nelson, and Walsh, 2002) confirms the importance of academic research for corporate innovation.

Work based on patent data corroborates the survey-based findings. Narin et al. (1997) count the number of scientific publications cited in US patents and interpret these as knowledge flows from science to industry. They show that the number of scientific references cited in patents increases three fold over a six-year period. The authors interpret their findings as evidence that US industry increasingly relies on the results from publicly funded research.

Following the work by Narin, Hamilton, and Olivastro (1997), a series of studies examines the impact of academic research on corporate performance. All these empirical studies summarized in Table 1, use various measures to proxy for an academic input on a corporate outcome and show that (i) basic science improves the corporate outcome, (ii) there is an intensification of the interactions between universities and firms over time, (iii) these links are highly concentrated in a small subset of technological fields, and (iv) they are geographically restricted.

Authors	**Data**	**Academic input**	**Corporate outcome**	**Findings**
Cockburn and Henderson (1998)	Ten US pharmaceutical firms, 1980-1988	Co-authorship of scientific papers between academic and industrial scientists	Number of patents	Connection to basic science increases firms performance in drug discovery
Siegel, Waldman, and Link (2003)	Survey of 177 UK firms, 1992	Location on a science park	New products, patents, copyrights	Firms located on science parks have higher research productivity
Cassiman, Veugelers, and Zuniga (2008)	79 Flemish firms (1186 patents), 1995-2001	- Co-authorship of scientific papers between academic and industrial scientists - citations to scientific papers	Number of patent citations	Firm's link to science is correlated with number of forward citations in patents
Nagaoka (2007)	56,660 US patents (1329 firms), 1983-2002	Citations to scientific papers	Number of patent citations	Firm's use of scientific references is correlated with forward citations in patents
Czarnitzki, Hussinger, and Schneider (2011)	4,973 German patents	Co-inventorship between academic and industrial scientists	Number of patent citations	Involvement of academic researcher in corporate patents is correlated with forward citations

3.2.2. Skills

We saw that research-based education is linked to growth through innovation in empirical work at the macro level. Survey data of individual inventors show that inventors tend to be highly educated. Giuri et al. (2007) report that 77% of European inventors have a university degree and that 26% of those inventors have a PhD.

There are few studies that address the question at the micro-level. Toivanen and Väänänen (2016) perform one such analysis using Finnish register data matched to patent data. They study the effect of university engineering education on inventive productivity, as measured by patents and their quality. They use data on U.S (USPTO) patents matched to individual level data on the whole Finnish working population over the period 1988 –1996. Their results show that there is a strong positive effect of engineering education on the propensity of individuals to patent. Three university engineers are needed to produce one additional patent. They also show that if Finland had not established three new engineering schools post-war, the number of patents obtained by Finnish inventors would have been 20% lower.

Caroli and Van Reenen (2001) perform a study on British and French firms and find that an important non-technological growth driver is organizational changes. Moreover, the authors find that organizational changes are skill-intensive, which implies that the growth effect of these activities is present in skill-intensive firms but not in non-skill-intensive firms. Moreover, Junge, Severgnini, and Sørensen (2015) use Danish firm-level data matched to an innovation survey to distinguish between different types of innovations carried out by those firms. They focus on the skill-intensity of the firms, measured by the share of employees with at least 16 years of formal education, as a driver of successful innovation. They find that innovation activities generate higher productivity growth rates in skill-intensive firms, those with high shares of employees with at least 16 years of formal education. By contrast, this effect is absent in non-skill-intensive firms.

Using Danish data, Junge and Sørensen (2010) study the relationship between employees with at least 16 years of education within different types of education for the probability to perform different types of innovation. They find that firms with high shares of employees with master's degrees within technical and social sciences tend to have more product innovation, whereas firms with high shares of employees with master's degrees in humanities have a higher likelihood to carry out marketing innovation.

These studies suggest that research-based education is important for firm performance; also for firms with innovation activities but no corporate R&D or no universities linkages. Such firms therefore need absorptive capacities through university-trained employees.

3.3. Channels of Industry-science linkages

There are multiple pathways through which spillovers from academic research may occur. This section provides an overview of the evidence for various channels. Since spillovers do not leave a paper trail, the choice of topics obviously entails a bias in favor of the channels that are more easily measured. Åstebro and Bazzazian (2011), Rothaermel, Agung, and Jiang (2007), Veugelers and Del Rey (2014), Siegel, Veugelers, and Wright (2007) provide useful reviews of this vast literature.

3.3.1. R&D collaboration

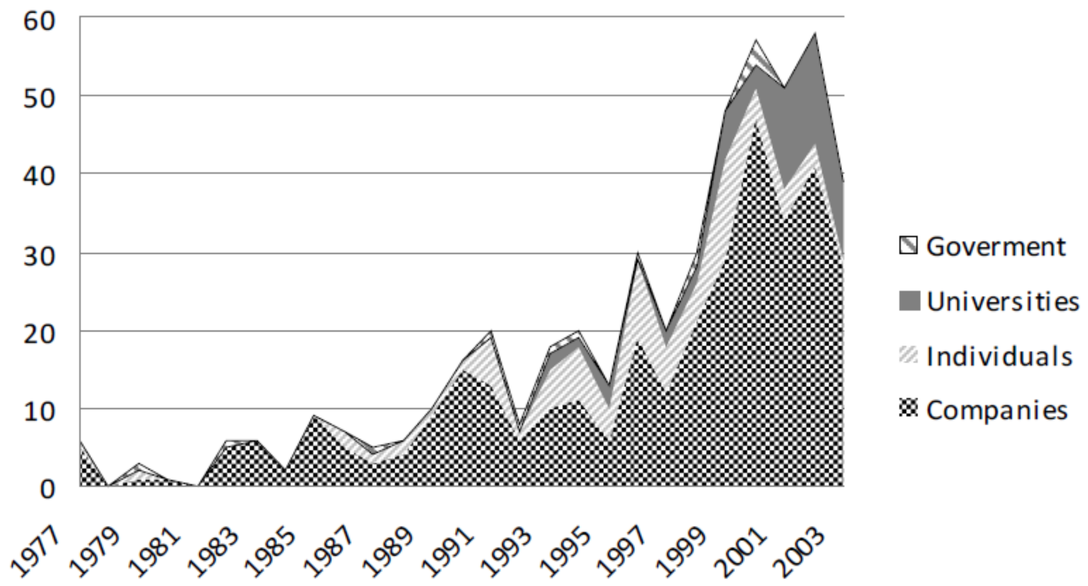
There is a substantial literature analyzing the firm-level determinants of university-industry collaborative research (Hall, Link, and Scott, 2003; Mohnen and Hoareau, 2003; Belderbos, Carree, and Lokshin, 2004; Belderbos et al., 2004; Veugelers and Cassiman, 2005). This literature shows that firms involved in R&D collaboration with universities are typically large firms in science-based industries that involve "new" science (e.g. biotechnologies, pharmaceuticals and ICT), with a strong absorptive capacity allowing them to commercially exploit the outcome of the collaborative agreement. Hall, Link, and Scott (2003) review the literature and identify two industry motivations for industry/university research joint ventures (RJVs). The first is access to complementary research activity and research results; the second is access to key university personnel. University motivation, on the other hand is largely financially based.

Using a survey of 2,056 Dutch firms over the period 1996-1998, Belderbos et al. (2004) analyze the success of partner-specific R&D collaboration on various measures of labor productivity growth. They show that cooperative R&D has the expected positive effect on firm performance. When they differentiate between the type of R&D partner (competitors, suppliers, customers, and universities and research institutes), they find that cooperation with suppliers and competitors have a significant impact on labor productivity growth, while cooperation with universities and research institutes positively affects the growth of sales of products and services that are new to the market. They interpret their result as a sign that cooperation with competitors and suppliers is focused on incremental innovations, improving the productivity performance of firms, while cooperation with universities is aimed at creating and bringing to market radical innovations, generating sales of products that are new to the market.

3.3.2. Academic patenting and licensing

The trend of a more prominent role of universities in technology development and the rise of the entrepreneurial university is perhaps best reflected in the growing number of patents generated by academic researchers. Denmark is no exception to this global trend. Figure 1, from Lissoni et al. (2009), shows the evolution of the number of patents listing a Danish academic inventor (i.e. employed by a Danish university), applied for at the European Patent Office (EPO)[7]. Over the last two decades, the number of academic patents almost quadrupled, in line with the evidence for other countries (see e.g. Veugelers et al., 2012). Although the number of academic patents is small, it rose faster than the overall number of patents.[8] Another striking feature is that most patents with an academic inventor (about 70 %) are actually owned by private firms. This pattern is consistent with practices in other European countries, where private companies (usually the sponsor of the research project) retain ownership right of the patents.

Figure 1: Academic Patenting in Denmark (source: Lissoni et al, 2009)



[7] Lissoni et al. (2009) match EPO patent data to Danish academics active in 2001 and/or 2005. The number of academic patents is therefore likely biased downwards and towards the most recent years.
[8] We will return to this topic in the Danish context in Section 4.4.1

Academic patenting is not only a small, but growing, occurrence, it is also concentrated in a small number of universities, in a small number of countries who account for the bulk of university patents.

One way of assessing the impact of university patents is to examine those that were subsequently licensed for commercial exploitation (e.g. Link, Scott, and Siegel, 2003). Licensing revenues are even more concentrated than the mere number of patents. Thursby and Thursby (2007) report that only 0.48 percent of all active patents licensed by US universities generated revenues of $1 million or more. Scherer and Harhoff (2000) show that the top ten percent of all Harvard patents provided 84 percent of the gross economic value of Harvard's patent portfolio. These are spectacular returns but rare occurrences.

Licensing is a restrictive operationalization of valorization, as it requires a monetary transfer to be recorded. An alternative approach is to look at the number of times an academic patent is cited by subsequent patents, a measure of that patent's technological impact. Henderson, Jaffe, and Trajtenberg (1998) show that averaged over the period 1965-1988, US University patents are both more important (as measured by the number of times they were cited) and more general than a random sample of corporate patents, but that this difference has been declining over time. Their result suggests that the observed increase in university patenting reflects an increase in those universities' propensity to patent rather than an increase in the output of important inventions. Studies using data for European countries reveal a similar trend: university and academic patents have, on average, a higher technological impact than corporate patents, but the difference between both groups has been declining over time (see e.g. Czarnitzki, Hussinger, and Schneider, 2011).

3.3.3. Inter-sectoral mobility

The mobility of academic scientists from academe to the private sector is a critical mechanism of knowledge transfer from basic to corporate research. The only evidence on labor mobility from academia to business comes from a series of studies published by Zucker, Darby and colleagues (e.g. Zucker, Darby, and Brewer, 1998) on the impact and role of star scientists in the development of the US biotechnology industry. They model the probability of a "star scientist" moving from academia, to a private company. By gaining access to the intellectual human capital of academic scientists, particularly of "star" scientists, firms achieve greater patent productivity and commercialization success (Zucker, Darby, and Torero 2002). Their paper shows that scientists are faster to move from academe to commercial involvement if they have higher-quality intellectual human capital (measured by the scientists' article citation counts) and if that capital is more relevant to firms commercializing biotechnology. They also show a strong effect of the opportunities available in the star's own region: stars have a higher probability of moving to a firm when there are more biotech enterprises in their region and a lower probability of moving to a firm when there are more top-quality universities in their region.

Because of the lack of large databases on labor mobility of university scientists, large scale studies on the inter-sectoral mobility of researchers between universities and firms are rare. Using the Danish register data, Ejsing et al. (2013) perform one such study and concentrate on the mobility of public university researchers to the private sector. They find that firms hiring university scientists become more innovative. Their results suggest that university scientists not only contribute to the firms' R&D activities, but they are also an important conduit to better absorb external R&D.

3.3.4. Academic spin-offs

A different type of movement from academe to business involves an academic entrepreneur to create a new venture, an academic spin- off, to commercialize public research.

Empirical analyses of university spin-offs rely on surveys from the US AUTM and their European counterparts, ASTP. These data confirm the US superiority in generating university spin-offs, even when correcting for the differences in research expenditures available to US universities compared to Europe. (Arundel and Bordoy 2006) show that US universities create 2.55 times more spin-offs than European universities for every million dollars spent in research expenditures.

Di Gregorio and Shane (2003) study the determinants of spin-off creation using the AUTM data from 101 universities and 530 startups. They find that the two key determinants of the number of start-ups by universities are (i) the research quality of its faculty and (ii) university policy of making an equity investment in lieu of requiring reimbursement of patenting and licensing expenses. Zhang (2009) finds that spin-off tends to stay close to the university, which suggests that technology transfer through spin-offs is to a high extent a local phenomenon.

Few studies investigate the performance of academic spin-offs. Zhang (2009) shows that university spin-offs have a higher survival rate but are not significantly different from other start-ups in terms of the amount of venture capital raised, the probability of completing an initial public offering (IPO), the probability of making a profit, or the number of employees.

3.3.5. Student spin-offs

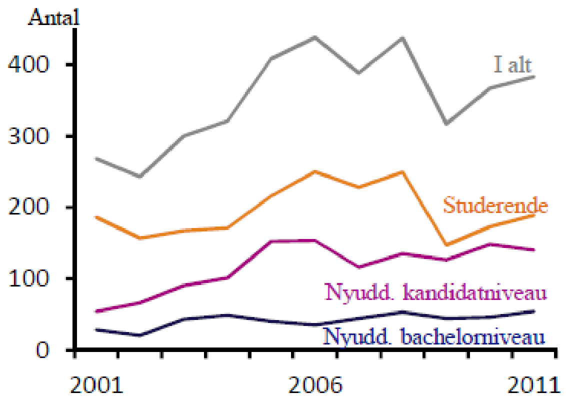
The empirical evidence on technology transfer almost exclusively covers patents and start-ups by faculty. Existing empirical work does not cover firms started by students because these are typically not using IP based on university funding. Nevertheless, student spin-offs are one of (the many) pathways through which the knowledge that students acquire from research based education, can be converted into direct and visible value to society.

There are no general data on the rate by which students start up new businesses upon graduation, but there are several university-specific alumni surveys. Åstebro and Bazzazian (2011) show that there are more student spin-offs than faculty spinoffs in the US. Their calculations for the MIT case, admittedly an outlier, indicate a student-to-faculty spin-off ratio from 12:1 to up to 48:1.

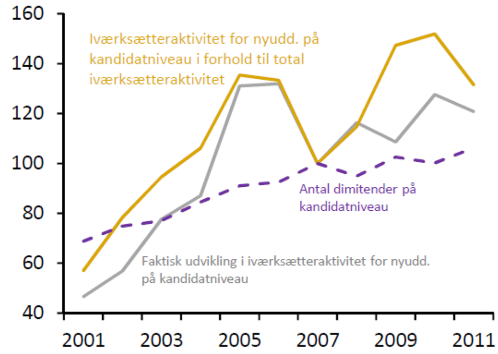
Figure 2 shows some evidence for Denmark (FI 2014) based on register data for the period 2001-2011. FI (2014) shows that:

- The number of student spin-offs rose by 43% over the period 2001-2011
- Graduates with a master's degree account for ¾ of the growth in the number of student spin-offs
- The growth in the number of student-spinoffs is three times higher than the growth in the total number of graduates
- New graduates create firms at a higher rate than the rest of the Danish population
- Student spinoffs experience higher productivity, employment and sales growth than other types of newly founded firms.

Figure 2: Students Spin-offs in Denmark (source: FI, 2014)



Kilde: Særkørsel på registerdata af Danmarks Statistik



Notes:
(1) ”*Nyudd. Bachelorniveau*”=number of firms created by newly graduated bachelors (within two years after graduation)
(2) ”*Nyudd. kandidatniveau*”=number of firms created by newly graduated masters and PhDs (within two years after graduation)
(3) ”*studerende*”=number of firms created by registered students
(4) ”*I alt*”= (1)+(2)+(3)

Notes:
(1) ”*Iværksætteraktivitet for nyudd. på kandidatniveau i forhold til total iværksætteraktivitet*”= number of firms created by newly graduated Masters relative to the total number of new firms created (base: 2007=100)
(2) ”*Antal dimitender på kandidatniveau*”=Number of graduates at the master’s level (base: 2007=100)
(3) ”*Faktisk udvikling i iværksætteraktivitet for nyudd. på kandidatniveau*”= Number of firms created by newly graduated masters (base: 2007=100)

3.4. Policies to improve industry-science links and education

3.4.1. IPR policies

In 1980, the U.S. introduced the Bayh-Dole Act which is arguably the most influential public law shaping university-based invention and commercialization practices in the U.S. and around the world. The key component of the Bayh-Dole model is granting the university, not the inventor, ownership rights to patentable inventions discovered using public research funds.

Based on the perceived success of the Bayh-Dole Act, this legislation has evolved into a “model” of university intellectual property policy that is currently being emulated and debated in many countries around the world. A 1999 legislative change (Lov om opfindelser ved offentlige forskningsinstitutioner) abolished the Danish “Professor’s privilege” that allowed academics to retain ownership of their patents in favor of a university ownership of patent rights.

Many observers credit laws inspired by Bayh-Dole with spurring university patenting and licensing that, in turn, stimulated innovation and entrepreneurship (Stevens 2004). Yet others argue that conflicting objectives and excessive bureaucracy make university ownership ineffective (Kenney and Patton 2009; Kenney and Patton 2011), the incentives for academic researchers to collaborate with corporations decreases (Valentin and Jensen 2007), or even overall university technology transfer decreases under the university ownership model (Czarnitzki et al. 2016).

3.4.2. Technology Transfer Offices (TTOs)

The motivation for the Bayh-Dole Act was to speed up technology transfers from universities to the market place. Presented with a new source of potential revenue, U.S. universities targeted resources to file and license their patents by establishing dedicated Technology Transfer Offices (TTOs). Many European universities followed this model by setting up their own TTOs, often with the support of public subsidies.

The possible benefits of TTOs include increased incentives for faculty to develop new technologies, additional revenue to the universities and wider diffusion of research results. Potential drawbacks include a shift away from fundamental research towards more applied activities and decreased diffusion through exclusive licensing agreements.

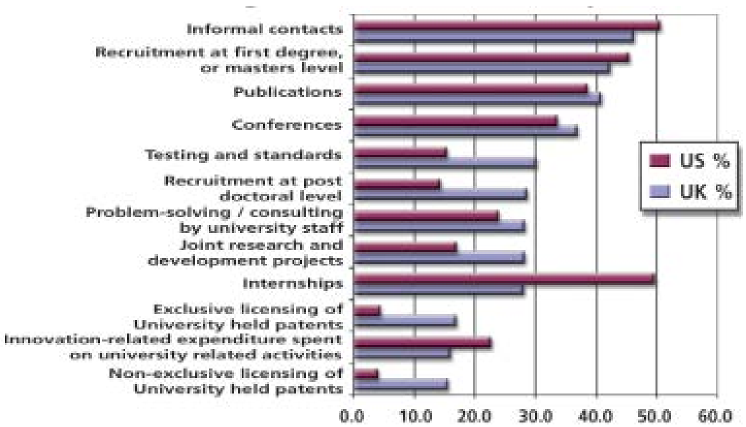
The evidence on the effect of the growth in university patenting and licensing is mixed. (Thursby and Thursby 2007; Thursby and Thursby 2002) review the evidence for the U.S. and find no evidence of a shift from basic to more applied research activities. Jensen and Thursby (2001) show that most licenses cover embryonic research and these licenses are often necessary for commercial exposure and success. Zucker and Darby (1996) find that star scientists in biotechnology have outstanding research records even after involvement in patenting and other forms of commercialization activities. Azoulay, Ding, and Stuart (2009) find that academic patenting is positively related to subsequent publication rates and on the quality of the published research. They do, however, find that academic patentees are shifting their research focus to questions of commercial interest.

Veugelers and Del Rey (2014) argue that the economic significance of the technology transfer model has often been exaggerated. There are examples of universities earning spectacular returns from licensing revenues, but these examples are extremely rare. Cosh, Hughes, and Lester (2006) conduct a survey of UK and US firms asking those firms which type of interaction with universities is the most likely to contribute to their innovation activities. In both countries, licensing of university patents is the least frequently cited contributor to university-industry interaction contributing to innovation (see Figure 3).

There were also critics of the Technology transfer model in industry, where a common view is that university TTOs are difficult to deal with, not only in licensing publicly funded research, but also the terms under which industry would license results of industry-sponsored research (Thursby and Thursby, 2003)

The evidence even for the US shows that most of the TTOs fail to break even, lacking a sufficiently large deal flow (Åstebro & Bazzanini , 2011). There is no clear evidence on the effectiveness of these intermediaries and their role in improving industry science links. Most of the critical success factors for industry science links cannot be shaped by the TTOs. In the EU, most TTOs are small and lack the necessary critical resources to be effective (Polt et al. 2001).

Figure 3: Types of University-Industry Interactions Contributing to Innovation (source: Cosh et al., 2006)



Note: percentage of sample firms (~4000) who answered that the listed type of interaction with universities contributed to their innovation activity

Table 2 shows the key figures of technology transfer activities for all universities in Denmark. The number of licensing agreements is small; collaboration agreements represent a higher fraction of the Danish TTOs activities. The number of TTO employees has been increasing over the years and they are running a deficit in most years.

Table 2: Key Figures for Danish TTOs

	2007	2008	2009	2010	2011	2012	2013
Inventions and patents							
Disclosure of inventions	303	240	231	255	293	372	407
Transfer of rights	187	144	151	159	173	226	271
Patent applications	113	99	109	95	131	146	180
Patent grants	8	7	15	8	38	31	40
Commercial results							
Licensing agreements	26	36	29	48	58	42	61
Sales agreements	51	38	39	35	26	41	40
Option agreements	6	3	1	13	12	8	9
Spin-outs	8	8	6	10	6	18	15
Research collaborations							
Collaborations agreements with private companies	n.a.	n.a.	n.a.	1.193	1.300	1.557	1.438
Collaboration agreements with research councils, foundations and programs, etc. involving private companies	n.a.	n.a.	n.a.	827	853	817	758
Cooperation agreements with public authorities	n.a.	n.a.	n.a.	994	941	1.078	867
Accounts and staff							
Employees in FTE	42,8	38,3	46	50,5	51,4	69,2	74,2
Expenses (in DKK 1.000)	26.987	29.908	36.505	30.638	32.061	34.063	46.495
Revenues (in DKK 1.000)	26.750	32.505	29.182	42.845	24.487	24.018	23.699

Source: DU, 2013

3.4.3. Regional clusters

Regional clusters refer to geographically areas where firms and other institutions such as universities concentrate to exploit complementarities, economies of agglomeration and knowledge spillovers (Porter 1990; Krugman 1991). In this literature few papers ask if universities can support the formation of such clusters, with an emphasis on famous examples in Massachusetts and Silicon Valley.

Motivated by the success of high tech clusters in the U.S., governments in industrialized countries tried to stimulate the creation of technology clusters around universities, often called “science parks”, via tax credits or subsidies. Siegel, Westhead, and Wright (2003) match firms located on U.K. science parks with observationally equivalent firms off science parks to assess what benefit firms derive from the science park location. They find that firms located on university science parks have slightly higher research productivity than firms not located on university science parks, but the magnitude of these impacts are not large. Link and Scott (2003) show that the proximity to a university is positively linked with the growth of U.S. science parks and the probability that the academic curriculum will shift from basic toward applied research.

Moretti and Wilson (2014) study the effect of state-provided subsidies, in the U.S. for high-tech and life-science firms designed to spur innovation-based clusters. They find that the adoption of subsidies by a state raises its number of star-scientists, but this gain is mainly due to relocation of star scientists from other states. They also find that the policy mainly affects private sector scientists, with little effects on academic researchers.

3.4.4. Education policies

The production of university graduates may well be affected by funding policies as these can affect the number of individuals who graduate from university and supply skills in the labor market. However, little is known about how funding policies influence the output of university graduates. The economic literature on university education devotes substantial attention to the determinants of “university access” but relatively little attention to attainment of a degree or time to degree (Turner 2004). Bound and Turner (2007) and Bound, Lovenheim, and Turner (2010) find that while completion may be affected by student characteristics, university funding is more important in explaining completion.

Foley and Groes (2015) analyze how changes in exogenously provided funding at the university faculty level affect the students' graduation rate and labor market performance. They exploit the Danish universities institutional setup during the 1980s. The authors find that when funding per student increases, this has a positive effect on graduation rate, but no effect on the probability of having a job. They interpret this result with a model where higher funding per student leads to more students graduating, which then leads to a lower average ability among the graduating students. The decreasing average student ability will work in the opposite direction of the increase in student funding, and can result in a zero total average effect on labor market outcomes of an increase in funding per student.

4 Descriptive analysis

The descriptive statistics presented in this section are motivated by the findings from the literature review in Section 3. We will describe five aspects related to university research in five sub-sections. First, we present an overview of R&D activities in the Danish economy in 2014 and investigate the distribution of private R&D expenditures across industries and firms. The literature review showed that university research and private R&D are complementary inputs in the production of knowledge and that the impact of university research is higher in R&D-intensive industries and firms. This sub-section will point to areas where applications of university research are expected to have the greatest potential. We show that R&D expenditures are highly concentrated in relatively few firms within a narrow set of high tech industries.

Second, we investigate direct cooperation between universities and private firms. We want to investigate if large firms in science-based industries that involve “new” science are the typical firm involved in cooperation with universities as found in the literature. The issue is whether such cooperation is more common in high tech manufacturing industries, where “new science-based” industries are classified. We confirm that cooperation between firms and universities is more likely in high-tech manufacturing. However, we also found cooperation with universities to be important for firms in high-tech services. Moreover, we find that the 5 year growth rate of labor-productivity is higher in firms that cooperate with Danish universities.

Third, university graduates are an important output from universities. These graduates may play an important role for the production of knowledge in firms who employ them. We present descriptive statistics on the relationship between the employment of university graduates (see the list of universities in Appendix A) and innovation. We investigate how the employment of workers with a university degree relates to the firms’ innovation strategies. We show that firms with innovation activities are more frequent employers of university graduates than firms with no innovation activities. Moreover, we find that firms doing formal R&D employ more university graduates than firms with innovations but no R&D.

Fourth, we provide descriptive statistics for growth of labor productivity for firms with varying shares of university trained workers. The purpose is to investigate whether research-based education correlates with productivity growth. We find that the 5 year growth rate of labor-productivity is higher in firms employing high shares of university trained workers compared to firms with low shares of university graduates. This result is independent on the innovation strategies pursued by the firms. The growth differential, however, is higher in firms with innovation activities especially for firms doing formal R&D. In addition, we regress the 5 year labor productivity growth rate on the share of university educated employees and the share of non-university educated employees. Doing this we find a positive and significant correlation between the intensity of university graduate employment and subsequent labor productivity growth, and no significant correlation between labor productivity growth and the share of non-university educated employees.

Fifth, we investigate the size of innovation, a measure of how incremental or drastic an innovation is. This information is, however, only available for product innovation and for a relatively narrow sample of firms. Still, the descriptive analysis provides interesting information about the relationship between innovation height, employment of university graduates, and R&D. In particular, we find that firms doing R&D and firms with higher shares of university graduates produce more "drastic" innovations.

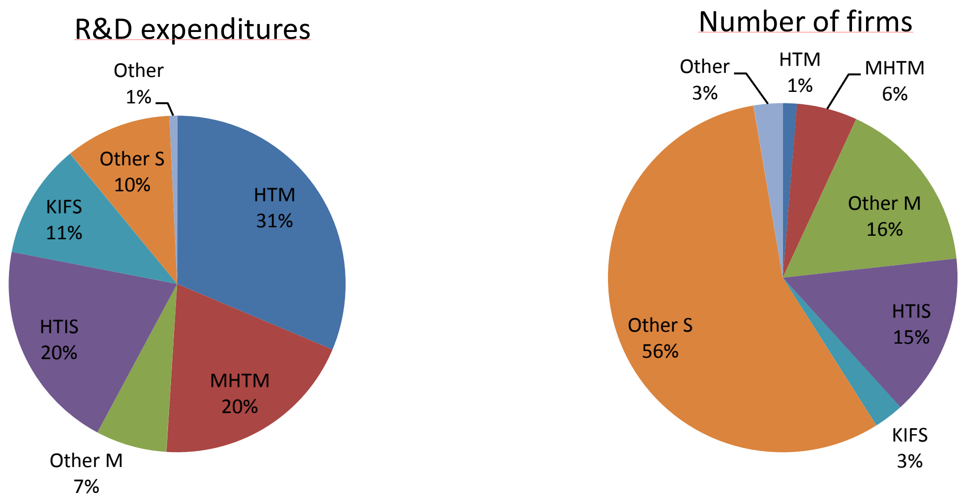
In the following we present the results. The results are presented for the entire private sector and for six more narrowly defined industries. We use an OECD technology classification described in Appendix B.

4.1 Private R&D

In this sub-section, we describe private R&D activities in the private sector in Denmark. The motivation point is that university research and private R&D constitute complementary inputs in knowledge production; and that the impact of university research is higher for R&D intensive industries and firms. Consequently, we want to point out areas where R&D intensity is high. We use Eurostat's Community Innovation Survey (CIS) covering innovation activities in 2014 and collected by Statistics Denmark.

In Figure 4, we present the distribution of private R&D expenditures broken down in six industries defined by the OECD, see Appendix B.

Figure 4: Distribution of own R&D expenditures and the number of firms across industries

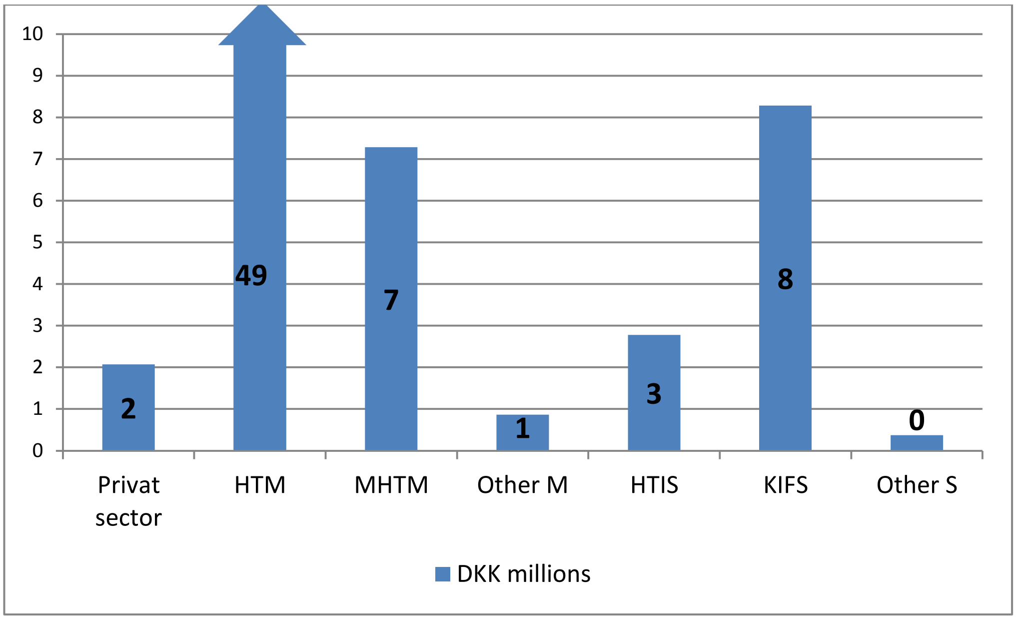


Note: HTM: High Tech Manufacturing, MHTM: Medium High Tech Manufacturing, Other M: Other Manufacturing, HTIS: High Tech Knowledge Intensive Services, KIFS: Knowledge Intensive Financial Services, Other S, Other Services and Other: Other sectors. See Appendix B for details.
Source: Community Innovation Survey, 2014, Statistics Denmark.

Figure 4 shows that R&D expenditures are concentrated in high-tech and medium-high tech industries. High tech manufacturing (HTM) account for almost one third of total private R&D, but they only represent one percent of the firms in the private sector. Medium-high tech manufacturing (MHTM) and high tech knowledge intensive services (HTIS) contribute 20 percent of aggregate R&D expenditure each, whereas they account for 6 and 15 percent of firms in the private sector.

In Figure 5, we present the average R&D expenditure in the six industries. Again, high tech industries stand out.

Figure 5: Own R&D expenditures per firm, DKK millions per firm, 2014

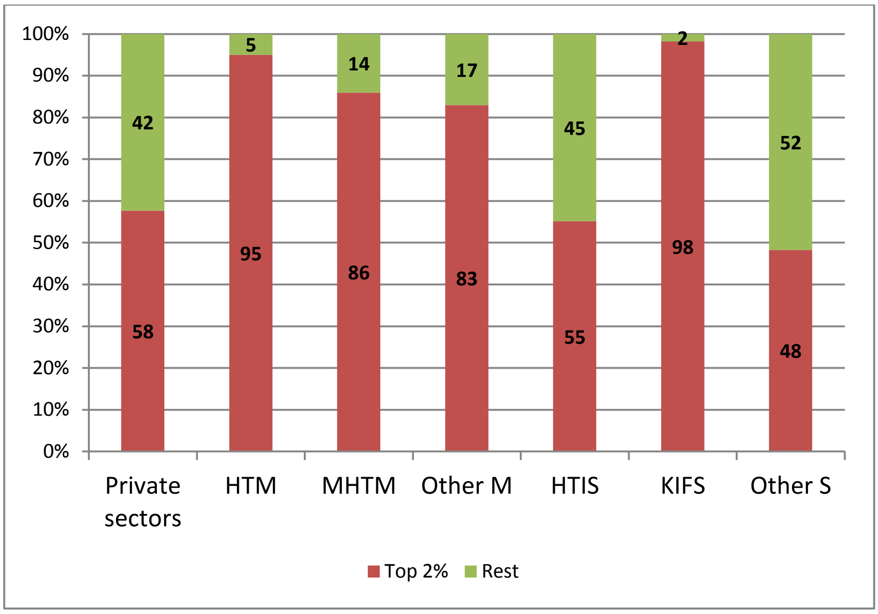


Note: HTM: High Tech Manufacturing, MHTM: Medium High Tech Manufacturing, Other M: Other Manufacturing, HTIS: High Tech Knowledge Intensive Services, KIFS: Knowledge Intensive Financial Services, Other S, and Other Services. See Appendix B for details.
Source: Community Innovation Survey, 2014, Statistics Denmark.

Firms spend, on average 2 million DKK on R&D. In high tech manufacturing (HTM) the average firm spent 49 DKK millions in 2014, whereas this number was 7, 8, and 3 DKK millions in medium high tech manufacturing (MHTM), knowledge intensive financial services (KIFS) and high tech knowledge intensive services (HTIS), respectively.

In Figure 6, we present the share of aggregate R&D expenditure that the top 2 percent R&D spenders account for. We present data for top 2 percent and not top 1 percent because there are too few firms in the top 1 percent to be allowed to be reported due to data confidentiality.

Figure 6: Share of aggregate R&D expenditures that top 2 percent firms stand for, 2014



Note: HTM: High Tech Manufacturing, MHTM: Medium High Tech Manufacturing, Other M: Other Manufacturing, HTIS: High Tech Knowledge Intensive Services, KIFS: Knowledge Intensive Financial Services, Other S, and Other Services. See Appendix B for details.
Source: Community Innovation Survey, 2014, Statistics Denmark.

Top 2 percent R&D spenders account for 58 percent of R&D expenditures in the private sector. This implies that relatively few firms contribute to aggregate R&D expenditures. This pattern is even more striking for many of the more narrowly defined industries. For example, top 2 percent R&D spenders contribute with 95 percent of R&D spending in high tech manufacturing (HTM) and 86 percent in medium high tech manufacturing (MHTM). For high tech knowledge intensive services the share is not so skewed and the top 2 percent spenders only account for 55 percent of R&D spending.

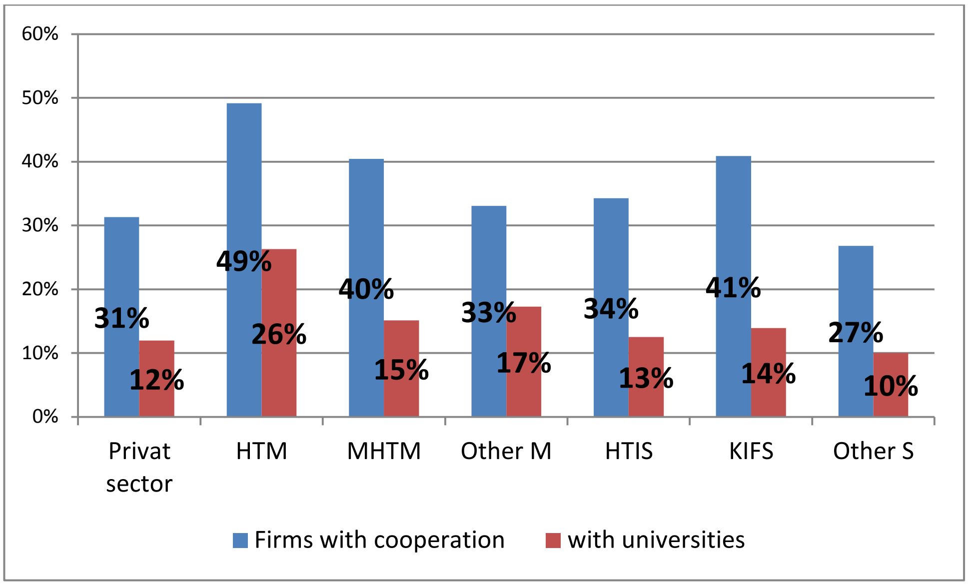
We end this subsection by concluding that a high share of aggregate R&D is covered by high tech and medium high tech industries, where 71 percent of aggregate R&D activities take place. Moreover, the high tech and medium high tech industries – especially high tech manufacturing – have high average R&D per firm. Finally, relatively few firms have high R&D expenditures and capture a large share of aggregate R&D expenditures.

4.2 Direct Collaboration

Next, we turn to collaboration between firms and universities. This is one mechanism through which universities can channel their knowledge directly into the private sector and the only one where we have relevant data. Firms are asked in the CIS questionnaire whether they have cooperated with universities and how important that cooperative agreement was for the development of ideas and completion of innovation projects.

Figure 7 presents the share of firms that cooperate with external partners on their innovation projects. Also the more narrow measure of the share of firms that cooperates with universities is presented.

Figure 7: Share of firms with cooperation with external partners and with universities and other knowledge institutions, 2014

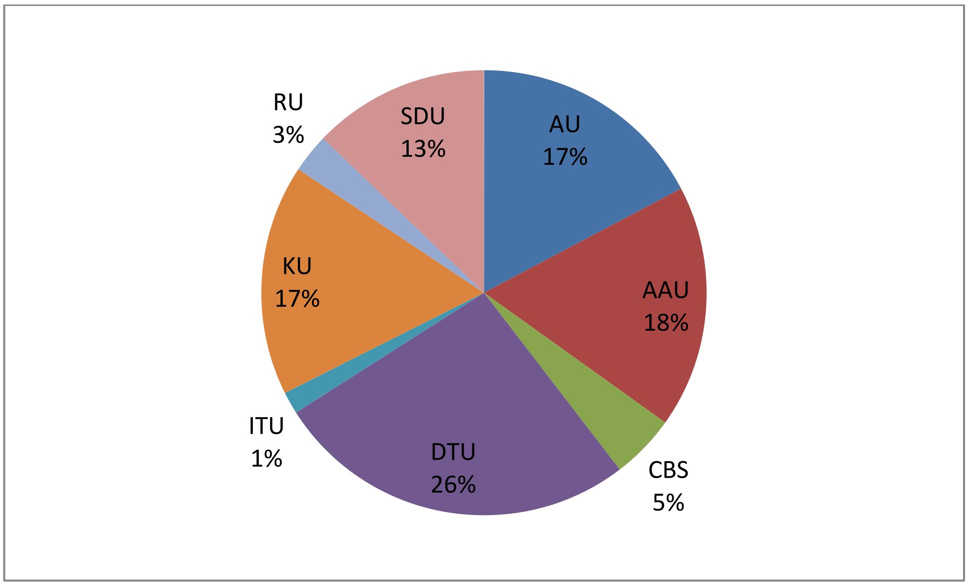


Note: HTM: High Tech Manufacturing, MHTM: Medium High Tech Manufacturing, Other M: Other Manufacturing, HTIS: High Tech Knowledge Intensive Services, KIFS: Knowledge Intensive Financial Services, Other S, and Other Services. See Appendix B for details.
Source: Community Innovation Survey, 2014, Statistics Denmark.

Almost a third of the firms cooperate with external partners, whereas 12 percent of firms cooperate with universities.

In Figure 8, we present the distribution of collaboration across Danish Universities. The highest shares are for the Technical University of Denmark, Aalborg University, Aarhus University, and University of Copenhagen.

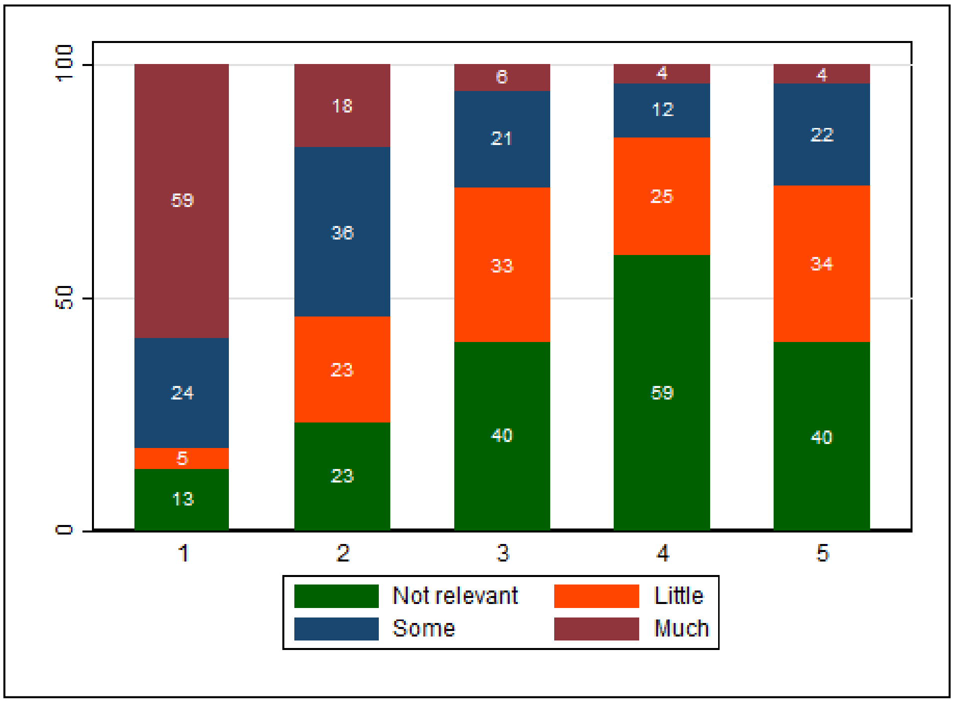
Figure 8: Collaboration between Firms and University. Shares for the 8 Danish Universities, 2014



Note: AU: Aarhus University, AAU: Aalborg University, CBS: Copenhagen Business School, DTU: Technical University of Denmark, ITU: IT-University of Copenhagen, KU: University of Copenhagen, RU: Roskilde University, SDU: University of Southern Denmark
Source: Community Innovation Survey, 2014 (Statistics Denmark).

In Figure 9, we present data for how important firms evaluate their collaboration for the development of ideas and completion of innovation activities. Cooperation with universities is not relevant for almost 60 percent of the firms. For the remaining 40 percent only 4 percent points consider collaboration with university to be important, whereas 12 percent points ascribes universities "some" importance.

Figure 9: Importance of Cooperation for Development of Idea and Completion of Innovation Activities, 2014



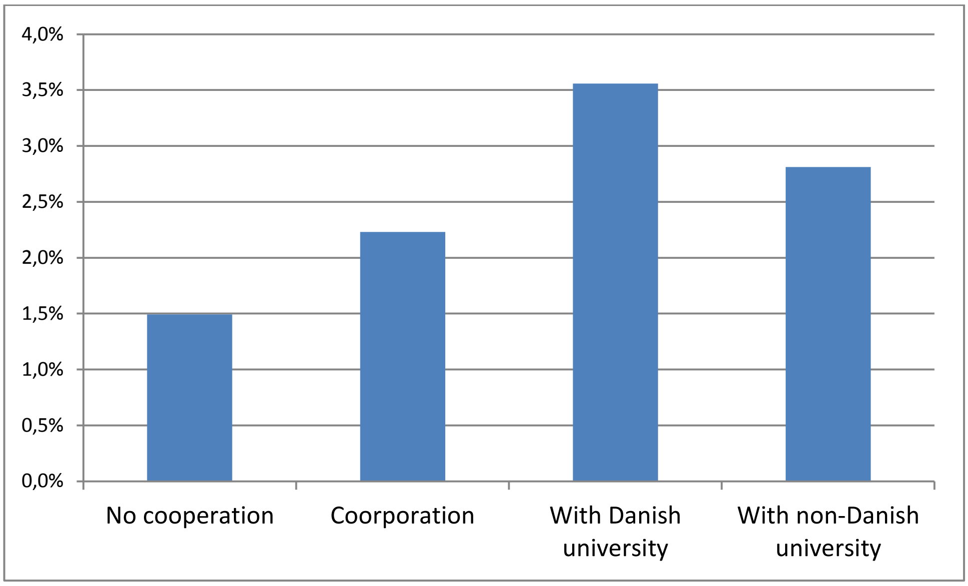
Note: Shares of responses within four categories. Numbers 1-5 refers to:1) Internal sources, 2) Business sector, 3) Advisors, 4) Research Institutions, 5) Other.
Source: Community Innovation Survey, 2014 (Statistics Denmark).

Finally, we introduce measures of productivity growth in addition to information on cooperation between firm and external partners. The purpose is to investigate correlations between productivity growth and cooperation with Danish universities.

We use the CIS data of Statistics Denmark from 2008 and firm accounting data for 2008 and 2013. Using these data we calculate the annualized 5 year growth rate of labor productivity as measured by value added per firm relative to employment of workers where employment is measured as full time equivalent employment such that a half-time worker counts for one half and a full-time worker counts as one.

In Figure 10, the average labor productivity growth rates of firms with different types of cooperation are compared. We apply 4 types: firms without cooperation, firms with any type of cooperation, firms with cooperation with a Danish university, and firms with cooperation with Danish and foreign universities.

Figure 10: Annual Labor Productivity Growth, 2008–13; Groups of Firms Divided after Types of Cooperation.



Source: Community Innovation Survey, 2014, accounting data (FIRM) 2013 (Statistics Denmark).

A number of interesting observations are seen from Figure 10. It is seen that firms with cooperation have higher average growth that firms without cooperation. Moreover, firms that specifically cooperate with a university have higher average growth than firms that cooperate in general. Also, firms that cooperate with a Danish university have higher average growth that firms that cooperate with a non-Danish university.

In Table 3 below, we perform a number of regressions. The purpose is to investigate the conditional correlation between initial cooperation and subsequent labor productivity growth rates when taking different types of cooperation into account simultaneous. The table includes three regressions. In column 1, general cooperation is correlated with productivity growth; in column 2, general cooperation and cooperation with Danish universities are correlated with productivity growth; and, finally in column 3, general cooperation, cooperation with Danish universities, as well as cooperation with non-Danish universities are correlated with productivity growth. It is found that the initial cooperation with Danish universities correlates significantly with subsequent labor productivity growth. The other types of cooperation do not correlate significant with labor productivity growth.

Table 3: Labor Productivity Growth and Cooperation. Change in log(value added/number of employees, full-time equivalent); 2008–13

	1	2	3
Cooperation in general	0.006	-0.001	-0.001
Cooperation with Danish university		0.020**	0.023**
Cooperation with non-Danish university			-0.014
R^2	0.027	0.031	0.032
Number of firms	1697	1697	1697

Notes: Changes in value added per FTE are annualized long changes 2008–13. Cooperation variables indicate type of cooperation during 2006-2008. All regressions include the growth rate of the capital intensity as measured by the capital stock in relation to full time equivalent employees and the growth rate in employment. Robust standard errors. *, **, *** denote significance at the 10%, 5%, or 1% level, respectively.
Source: Community Innovation Survey, 2014, FIRM 2013 (Statistics Denmark).

The results point to the fact that firms that cooperate with Danish universities are also high growth firms. This is not to say that the relation is causal. Still, there is a significant correlation and this observation calls for further investigations on the socioeconomic importance of cooperation with Danish universities. One obvious concern is that the indicator for university cooperation is an indicator for having R&D activities. However, even when including measures of R&D in the regression the significant correlation between cooperation with Danish universities and productivity growth is present (the results are not presented in the report).

The descriptive statistics presented in this sub-section suggest that about 12 percent of Danish firms have direct contact with universities. Moreover, results point to the fact that firms that corporate with Danish universities are also high growth firms.

4.3 University Education, Innovation, and R&D

In the following, we apply a broader focus and include both R&D and innovation as measures for knowledge production. In this respect it should be mentioned that innovation is an output measure, whereas R&D is an input measure. However, as we will show, many firms have innovation but no R&D activities. In other words, innovations take place in firms even without R&D activities. In this sense, we consider innovation to be a broader measure of knowledge production.

Before presenting the descriptive statistics, we describe our measures of knowledge production. First, we use an alternative measure for R&D activity to the one used in sub-section 4.1. Specifically, we use a variable describing whether firms have R&D-activities or not. Second, we use an indicator of whether firms have innovation activities or not. More precisely, firms are asked whether they have product or service innovation, process innovation, organizational innovation or marketing innovation.[9] We consider firms to have innovation if they have introduced innovations among one or more of the four innovation types. Using these definitions for knowledge production, we focus on three firm types: firms without R&D and innovation, firms with innovation but no R&D, and firms with R&D.

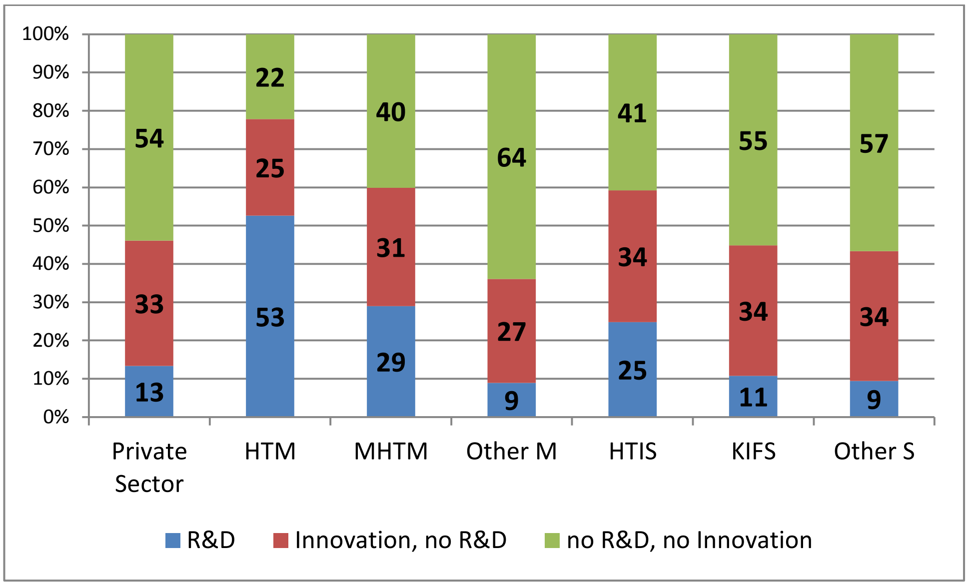
In addition to using a broader measure of innovation, we also introduce measures of labor input of firms. Specifically, we introduce the share of university educated employees out of the total number of employees in firms. Using this measure enables us to compare the intensity of university educated employees across firm types. If firms with knowledge production have higher shares than firms without knowledge production, this is an indication for knowledge production to be an activity that intensively uses university educated employees.

In Figure 11, we present the presence of the three firm types in the economy. For the private sector, it is seen that 13 percent of firms have R&D, 33 percent of firms have innovation, whereas 54 percent of firms have neither R&D nor innovation.[10]

[9] Firms are asked whether they have introduced innovations during the period 2012-2014. The question for R&D activities applies for 2014

[10] In Statistics Denmark (2015) it is shown that 44 percent of firms have innovation activities I 2014. In Figure 7, the share of firms with innovation activities also equals 44 percent since 2 percentage points of firms with R&D activities do not have innovation activities.

Figure 11: Firm Types across Industries; Firms with R&D, Firms with Innovation but without R&D, and Firms without R&D and without Innovation, 2014

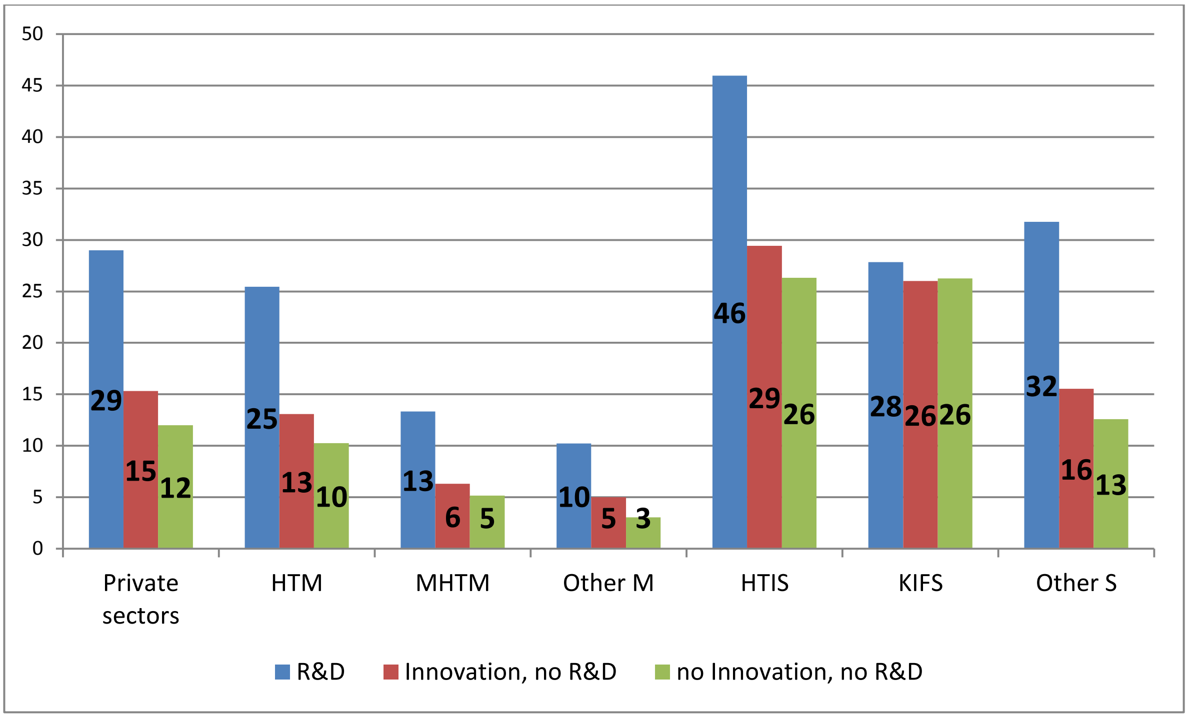


Note: HTM: High Tech Manufacturing, MHTM: Medium High Tech Manufacturing, Other M: Other Manufacturing, HTIS: High Tech Knowledge Intensive Services, KIFS: Knowledge Intensive Financial Services, Other S, and Other Services. See Appendix B for details.
Source: Community Innovation Survey, 2014 (Statistics Denmark).

For the six industries high tech and medium high tech have relatively many firms with knowledge production, especially, high tech manufacturing (HTM). The overall impression of Figure 10 is that many firms have innovation also firms not having R&D.

In Figure 12, we present the share of university educated employees out of total number of employees. The share is presented for the three types of firms; firms with R&D, firms with innovation and no R&D, and firms without innovation and R&D. For the private sector, it is seen that firms with R&D have a share of almost 30 percent, which is twice as high as that of firms with innovation but no R&D. Moreover, the share of university educated employees for firms with innovation but no R&D is higher than for firms without knowledge production. However, the difference is not as pronounced as for the two firm types with knowledge production. I.e., firms with knowledge production have a large share of university educated workers; especially those with R&D.

Figure 12: Share of University Educated Employees out of Total Number of Employees, 2014



Note: HTM: High Tech Manufacturing, MHTM: Medium High Tech Manufacturing, Other M: Other Manufacturing, HTIS: High Tech Knowledge Intensive Services, KIFS: Knowledge Intensive Financial Services, Other S, and Other Services. See Appendix B for details.
Source: Community Innovation Survey, 2014, Statistics Denmark, FIDA 2013 and Education Registers 2014 (Statistics Denmark).

Similar patterns within the six industries are found as for the private sector. The only exception is for knowledge intensive financial services (KIFS) where there is hardly any difference in the share of university educated employees across firm types.

4.4 Productivity growth, knowledge production and education

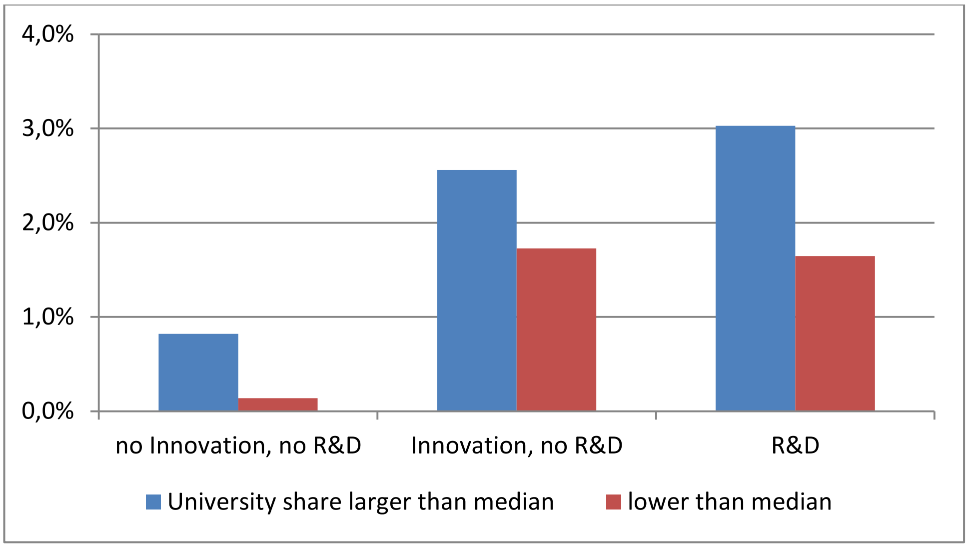
In this sub-section, we introduce measures of productivity growth in addition to information on university educated employees and knowledge production. The purpose is to investigate correlations between productivity growth, characteristics of labor input and knowledge production.

We use the CIS data from 2008 and data from the education registers from 2008 of Statistics Denmark. Using the information on knowledge production and university educated employees, we define six firm types: university education intensive firms with R&D, non-university education intensive firms with R&D, university education intensive firms with innovation but without R&D and so on. Firms are university education intensive if their share of university educated employees out of all employees is high. Specifically, we consider the share to be high for firms belonging to half that have the highest share. I.e., firms with a share that exceeds the median share within the relevant type of knowledge production.

Moreover, we use accounting data for 2008 and 2013. Using these data we calculate the annualized year growth rate of labor productivity as measured by value added per firm relative to employment of workers where employment is measured as full time equivalent employment such that a half-time worker counts for one half and a full-time worker counts as one.

In Figure 13, the average labor productivity growth rates of university educated-intensive firms are compared with the average growth rate of non-university educated-intensive firms. In particular, as discussed in the following paragraph, firms are organized in terms of their knowledge production activities.

Figure 13: Annual Labor Productivity Growth, 2008–13; Groups of Firms Divided after Types of Innovation Activities



Source: Community Innovation Survey, 2014, Education registers, 2014, FIDA, 2013, FIRM 2014 (Statistics Denmark).

One interesting observation may be gleaned from Figure 12. It is seen that for each type of firm, the average growth rate of university education-intensive firms is greater than the average growth rate of non-university education-intensive firms of the same type. This difference is found for all three firm types featured and thereby reveal positive correlation between initial intensity of university education and subsequent labor productivity growth rates.

In Figure 13, we only distinguish between firms by the university education intensity. However, firms may also employ workers with higher education that are not educated at universities. In other words, employees may have higher education from university or employees may have higher education from a non-university institution.

In Table 4 below, we perform a number of regressions. The purpose is to investigate the conditional correlation between initial university education intensities and subsequent labor productivity growth rates when taking the initial non-university education intensity into account. The table presents two regressions for each firm type. In the columns labelled a), the higher education intensity is included. This intensity does not distinguish between higher education from university and non-university institutions. In regressions 1a, 2a, and 3a, it is found that the initial higher education intensity correlates significantly with subsequent labor productivity growth. The estimated parameter is largest for firms with R&D and lowest for firms without knowledge production.

Table 4: Labor Productivity Growth and Initial Knowledge Production and Education Intensities. Change in log(value added/number of employees, full-time equivalent); 2008–13

	1a	**1b**	**2a**	**2b**	**3a**	**3b**
Knowledge production:	**Without innovation, without R&D**		**Innovation, without R&D**		**R&D**	
Education type:						
Higher education	0.018*		0.034**		0.045**	
University education		0.025		0.038*		0.064**
Non-university education		0.013		0.030		0.010
R^2	0.024	0.024	0.041	0.041	0.047	0.049
Number of firms	1323	1323	787	787	1119	1119

Notes: Changes in value added per FTE are annualized long changes 2008–13. Higher education is the higher education intensity as measured by the share of employees who possess at least a short further education in 2008; university education is the higher education intensity of employees educated from university; whereas non-university education is the higher education intensity of employees educated outside university. All regressions include the 5 year growth rate of the capital intensity as measured by the capital stock in relation to full time equivalent employees and the 5 year growth rate in employment. Robust standard errors. *, **, *** denote significance at the 10%, 5%, or 1% level, respectively.
Source: Community Innovation Survey, 2014, Education registers, 2014, FIDA, 2013, FIRM 2014 (Statistics Denmark).

Next, we split the higher education intensity into university education and non-university education. The university education intensity is found to be positive and significant for firms with knowledge production, see columns 2b and 3b. On the other hand, growth rates do not correlate significantly with the non-university education intensity. The initial university education intensity and the subsequent labor productivity growth rate are correlating positively and significantly even when the non-university education intensity is taken into account. For firms without knowledge production no significant correlation is present as seen from column 1b.

The descriptive statistics presented in this sub-section point to the fact that firms with knowledge production and intensive use of university educated employees are also high growth firms. This is not to say that the relation is causal. But there is a correlation and this observation calls for further investigations on the socioeconomic importance of research-based education. We will return to the discussion of this in Section 5 that presents suggestions for further studies.

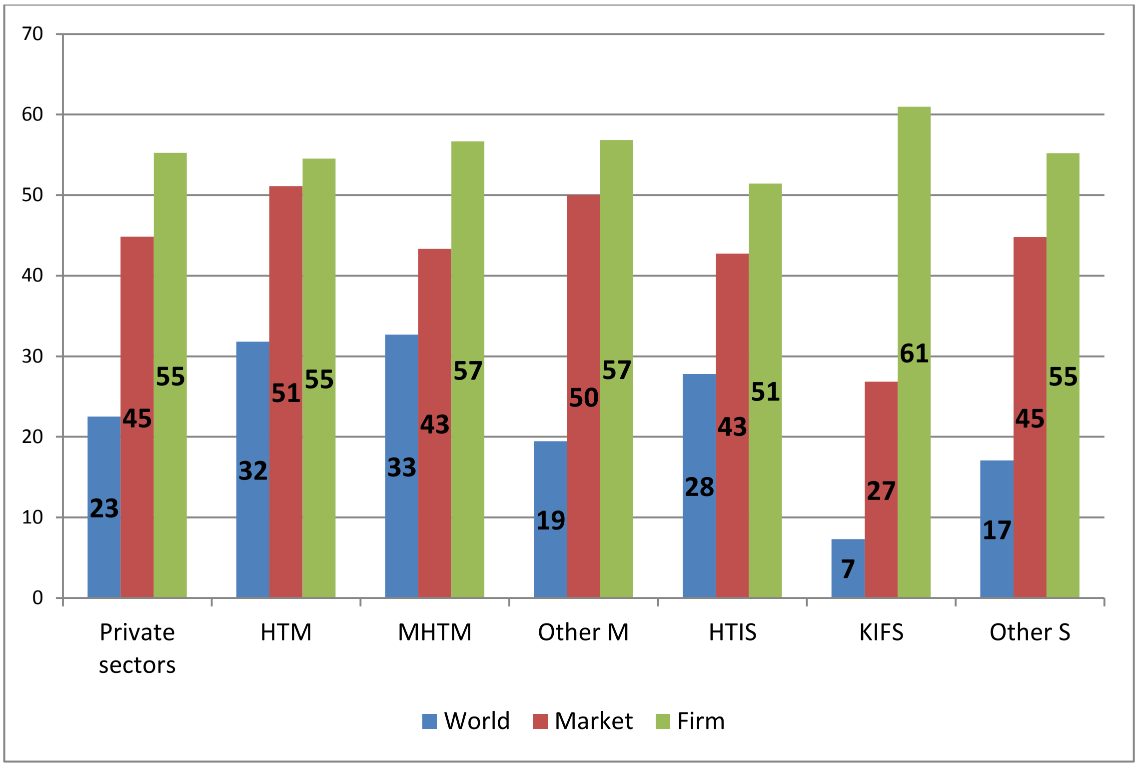
4.5 Size of innovation

A last aspect that we cover in this section is size of innovation; also called innovation height. Until now, we did not distinguish between “incremental” or more “drastic” innovations. In this subsection, we discuss the degree of novelty or size innovation of product innovations carried out by Danish firms in 2014.

The descriptive statistics presented in this section is based on CIS questions related to the newness of products and services that firms introduced. Specifically, firms answer survey questions on whether they have introduced products or services that are new to the world, new to the market or new to the firm. Moreover, they answer survey questions on their sales shares due to products or services that are new to the world, new to the market and new to the firm. In the following, we present descriptive statistics based on these questions. The sample is relatively limited as many firms in CIS do not answer these questions. The sample is not considered to be representative for Danish firms in general but is to a greater extent biased towards firms with knowledge production.

Figure 14 shows that 23 percent of firms in the sample introduce products or services that are new to the world, 45 percent of firms introduce products or services that are new to the market, whereas 55 percent of firms introduce products or services that are new to the firm.

Figure 14: Share of Firms that Introduces New Products and Services, 2014

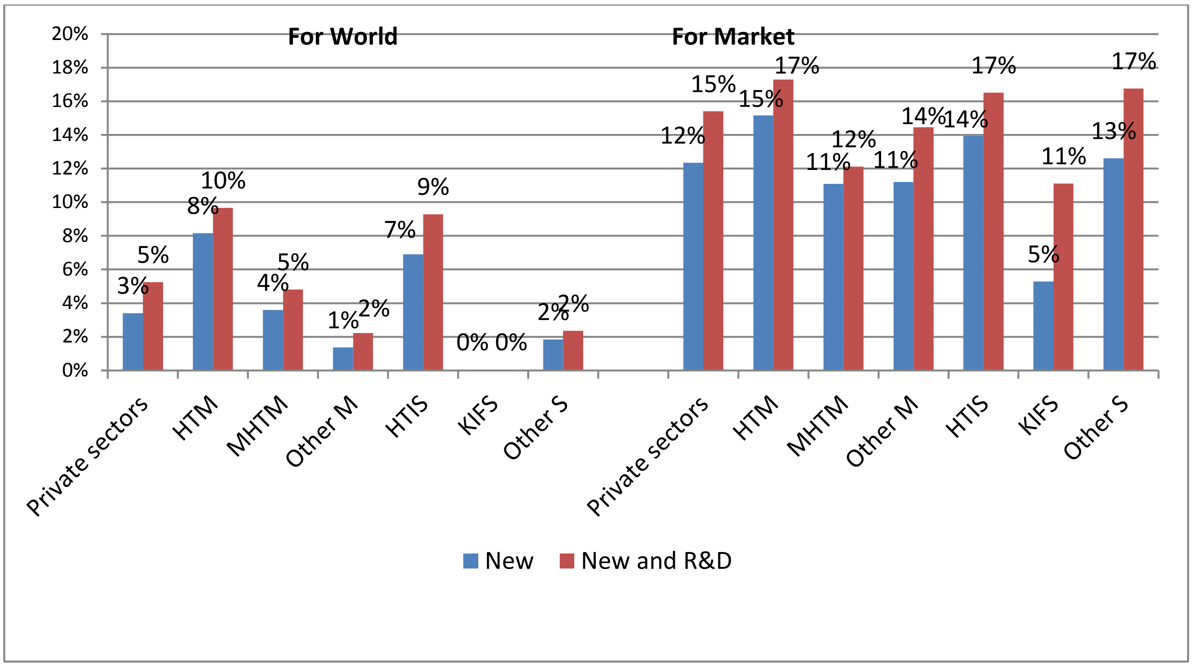


Note: HTM: High Tech Manufacturing, MHTM: Medium High Tech Manufacturing, Other M: Other Manufacturing, HTIS: High Tech Knowledge Intensive Services, KIFS: Knowledge Intensive Financial Services, Other S, and Other Services. See Appendix B for details.
Source: Community Innovation Survey, 2014 (Statistics Denmark).

The share of products and services that are new to the world is higher for high tech and medium high tech industries. For products and services that are new to the market or new to the firm, the pattern is less clear.

In Figure 15, we present the average sales share of new products and services broken down by firms with or without R&D. The average sales share for products and services that are new to the world is presented in the left part of the figure, whereas the average sales share for products and services that are new to the market is presented in the right part.

Figure 15: Average Sales Share of New Products and Services, 2014

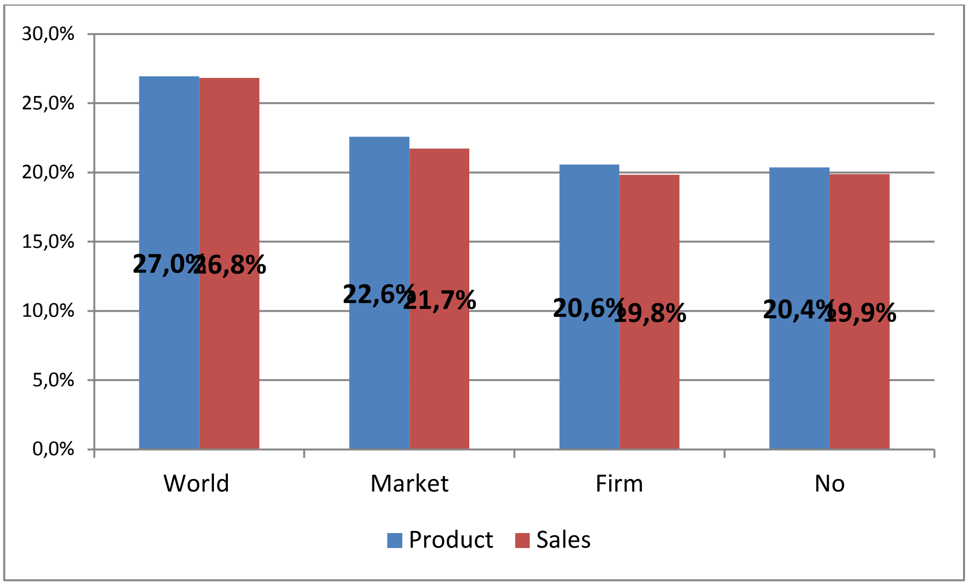


Note: HTM: High Tech Manufacturing, MHTM: Medium High Tech Manufacturing, Other M: Other Manufacturing, HTIS: High Tech Knowledge Intensive Services, KIFS: Knowledge Intensive Financial Services, Other S, and Other Services. See Appendix B for details.
Source: Community Innovation Survey, 2014 (Statistics Denmark).

The average sales share is higher for products and services that are new to the market and the firms with R&D have higher sales shares of new products and services than firms without R&D.

In Figure 16, we report the share of university educated employees out of the total number of employees by size of innovation. The share of university graduates is highest for products and services that are new for the world; second highest for products and services that are new for the market and similar for firms with products and services that are new to the firm and firms that have no innovation activities.

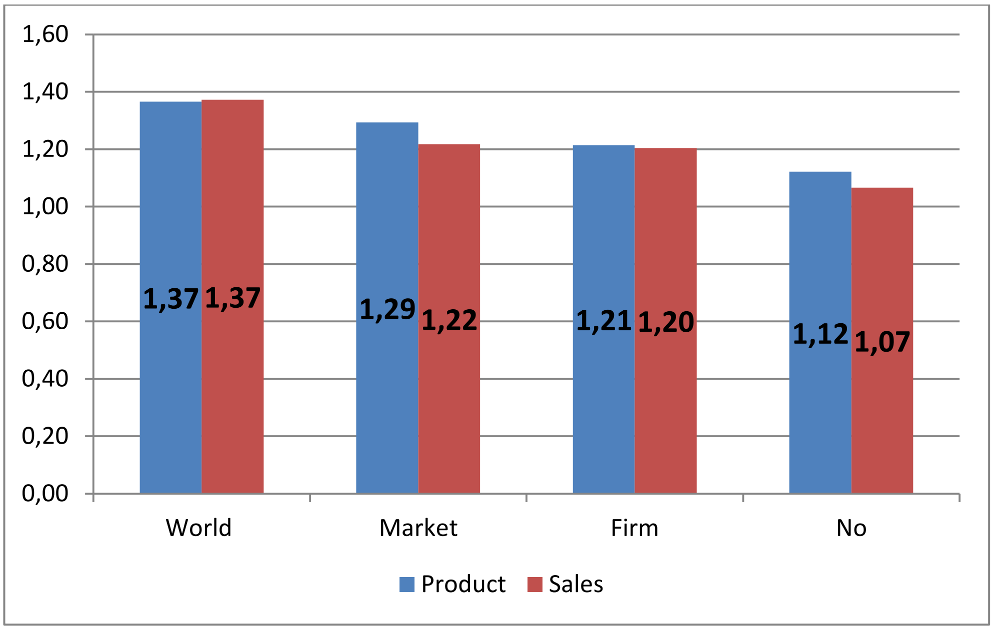
Figure 16: Share of University Educated Employees out of Total Number of Employees, 2014



Source: Community Innovation Survey, 2014, Education registers, 2014, FIDA, 2013, FIRM 2014 (Statistics Denmark).

Finally, in Figure 17 we report the ratio of university educated employees to the number of employees with non-university higher education. Firms that introduce new products or services with high size of innovation use more university educated employees per employee with non-university higher education.

Figure 17: University Educated Employees to Employees with Non-university Higher Education, 2014



Source: Community Innovation Survey, 2014, Education registers, 2014, FIDA, 2013, FIRM 2014 (Statistics Denmark).

Appendix A: List of Universities and institution numbers

Name of university	**Statistics Denmark code (INSTNR)**
University of Copenhagen	101455, 101441, 101582, 147410, 101443
Aarhus University	751431, 751418, 657410, 751451, 751465, 101535, 751422
Copenhagen Business School	147406
Technical University of Denmark	173405, 151409, 313402, 217404
Aalborg University	851416, 561408, 151413, 851412
University of Southern Denmark	461416, 621406, 537406, 330401, 561411
Roskilde University	265407
IT-University of Copenhagen	101530

Appendix B: High and Medium high technology industry classification

Industries		NACE Rev. 2 codes – 2-digit level
High-technology manufacturing (HTM)	21 26	Manufacture of basic pharmaceutical products and pharmaceutical preparations; Manufacture of computer, electronic and optical products
Medium-high technology manufacturing (MHTM)	20 27 to 30	Manufacture of chemicals and chemical products; Manufacture of electrical equipment; Manufacture of machinery and equipment n.e.c. ; Manufacture of motor vehicles, trailers and semi-trailers; Manufacture of other transport equipment
Other manufacturing (Other M)	19 22 to 25 33 10 to 18 31 to 32	Manufacture of coke and refined petroleum products; Manufacture of rubber and plastic products; Manufacture of other non-metallic mineral products; Manufacture of basic metals; Manufacture of fabricated metals products, excepts machinery and equipment; Repair and installation of machinery and equipment Manufacture of food products, beverages, tobacco products, textile, wearing apparel, leather and related products, wood and of products of wood, paper and paper products, printing and reproduction of recorded media; Manufacture of furniture; Other manufacturing
High-tech knowledge intensive services(HTIS)	59 to 63 72	Motion picture, video and television programme production, sound recording and music publish activities; Programming and broadcasting activities; Telecommunications; computer programming, consultancy and related activities; Information service activities; Scientific research and development;
Knowledge intensive financial services (KIFS)	64 to 66	Financial and insurance activities (section K).
Other service (Other S)	50 to 51 58 69 to 71 73 to 75 78 80 84 to 93 45 to 47 49 52 to 53 55 to 56 68 77 79 81 82 94 to 96 97 to 99	Water transport; Air transport; Publishing activities Legal and accounting activities; Activities of head offices, management consultancy activities; Architectural and engineering activities, technical testing and analysis; Advertising and market research; Other professional, scientific and technical activities; Veterinary activities (section M); Employment activities; Security and investigation activities; Public administration and defence, compulsory social security (section O); Education (section P), Human health and social work activities (section Q); Arts, entertainment and recreation (section R). Wholesale and retail trade; Repair of motor vehicles and motorcycles (section G); Land transport and transport via pipelines; Warehousing and support activities for transportation; Postal and courier activities; Accommodation and food service activities (section I); Real estate activities (section L); Rental and leasing activities; Travel agency, tour operator reservation service and related activities; Services to buildings and landscape activities; Office administrative, office support and other business support activities; Activities of membership organisation; Repair of computers and personal and household goods; Other personal service activities (section S);Activities of households as employers of domestic personnel; Undifferentiated goods-and services-producing activities of private households for own use (section T); Activities of extraterritorial organisations and bodies (section U).

Source OECD

Appendix C Tables used for figures

Table C1 Own R&D Expenditure, 2014

	Private sectors	High-tech manufacturing	Medium-high tech manufacturing	Other manufacturing	High-technology intensive services	Knowledge intensive financial services	Other services
Sector total (1,000 DKK)	36,265,044	11,374,649	7,129,817	2,473,991	7,328,842	3,990,961	3,701,680
Percent	100%	31.37%	19.66%	6.82%	20.21%	11.00%	10.21%
Number of firms	17,531	230	979	2,865	2,634	482	9,871
Firm average	2,069	49,487	7,284	863	2,782	8,287	375

Note: Used for Figures 4 and 5. Numbers are weighted using Statistics Denmark weights to aggregate to the economy level. Based on "Total costs for own R&D" (Variable name: u_total)
Source: Community Innovation Survey, 2014 (Statistics Denmark).

Table C2: Dispersion of Own R&D Expenditure, 2014

	Private sectors	High-technology manufacturing	Medium-high technology manufacturing	Other manufacturing	High-technology intensive services	Knowledge intensive financial services	Other services
Top 1%	51.81	NA	76.31	78.17	51.98	NA	45.47
Top 2%	57.71	95.01	85.98	82.95	55.16	98.18	48.24
Top 5%	65.27	97.43	90.69	88.01	63.81	99.88	51.76
Top 10%	67.72	98.71	93.59	91.09	67.67	100.00	57.93

Note: Used for Figure 6. Numbers are weighted using Statistics Denmark weights to aggregate to the economy level. NA: Not available due to data confidentiality. Based on "Total costs for own R&D" (Variable name: u_total).
Source: Community Innovation Survey, 2014 (Statistics Denmark).

Table C3: Cooperation with External Partners, 2014

	Private sectors	High-technology manufacturing	Medium-high technology manufacturing	Other manufacturing	High-technology intensive services	Knowledge intensive financial services	Other services
Number of firms with cooperation	2,487	86	230	348	504	85	1,137
Research institutions	955	46	86	182	184	29	426
Advisors	1,306	59	146	224	227	41	540
Internal sources	832	41	99	136	180	45	292
Other business sector	2,110	77	179	298	450	76	951
Public service	485	21	21	41	146	9	224
Number of firms without collaboration	5,456	89	339	704	967	123	3,106
Total number of firms	7,943	175	569	1,052	1,471	208	4,243

Note: Used for Figure 7. Numbers are weighted using Statistics Denmark weights to aggregate to the economy level. Based on the question "During the three years 2012 to 2014, did your enterprise co-operate on any of your innovation activities with other enterprises or institutions?" (Variable names: co_n (Number of firms with cooperation); inno_uni_, inno_forsk_ (Research institutions); inno_gts_, inno_konsulent_ (Advisors); virk_konc_ (Internal sources); soft_lev_, inno_kunde_, inno_kon_andre_, inno_andre_bran_ (Other business sector); inno_offt_, inno_sam_andre_ (Public service)).
Source: Community Innovation Survey, 2014 (Statistics Denmark).

Table C4: Cooperation with Universities, 2014

	Private sectors	High-technology manufacturing	Medium-high technology manufacturing	Other manufacturing	High-technology intensive services	Knowledge intensive financial services	Other services
Number of firms that cooperate with universities	947	44	82	166	183	26	406
University of Copenhagen	216	20	15	36	58	4	76
Aarhus University	270	13	21	25	71	*	126
University of Southern Denmark	195	7	27	24	44	*	84
Roskilde University	29	*	*	*	9	*	10
Aalborg University	261	13	47	48	43	11	89
Technical University of Denmark	359	25	38	64	91	*	124
IT-University of Copenhagen	21	3	*	*	10	*	*
Copenhagen Business School	57	*	*	6	14	3	30

Note: Used for Figure 8. Numbers are weighted using Statistics Denmark weights to aggregate to the economy level. Based on the question: "Which Danish universities – if any – did your firm cooperate with on innovation activities?" (Variable names: inno_sam_au, inno_sam_auc, inno_sam_cbs, inno_sam_dtu, inno_sam_itu, inno_sam_ku, inno_sam_ruc, inno_sam_sdu)
Source: Community Innovation Survey, 2014 (Statistics Denmark).

Table C5: Firm Types across Industries; Firms with R&D, Firms with Innovation but without R&D, and Firms without R&D and without Innovation, 2014

	Private sectors	High-technology manufacturing	Medium-high technology manufacturing	Other manufacturing	High-technology intensive services	Knowledge intensive financial services	Other services
R&D	2,345	121	284	256	654	52	933
R&D and innovation[1]	2,022	112	245	231	535	37	822
R&D and process and/or product	1,766	95	242	215	486	36	664
Innovation but no R&D	5,732	58	302	778	906	164	3,347
Process and/or product but no R&D	3,624	45	208	544	620	85	2,024
All firms[1]	17,531	230	979	2,865	2,634	482	9,871

Note: Used for Figure 10. [1)] Firms have innovation if they have product innovation, process innovation, organizational innovation or marketing innovation. Numbers are weighted using Statistics Denmark weights to aggregate to the economy level. Based on whether firms have R&D, product innovation, process innovation, marketing innovation or organizational innovation. A firm has innovation if it has product innovation, process innovation, marketing innovation or organizational innovation. (variable names: rrdin (dummy for R&D); inpdgd, inpdsv (product innovation); inpspd, inpslg, inpssu (process innovation); orgfor, orgwrk, orgext (organizational innovation); marinddsg, marpmv , marstg, marpla, markpris (marketing innovation)).
Source: Community Innovation Survey, 2014 (Statistics Denmark).

Table C6: Education Intensities

	Private sectors	High-technology manufacturing	Medium-high technology manufacturing	Other manufacturing	High-technology intensive services	Knowledge intensive financial services	Other services
Intensity of university-trained employees							
All	16.57	19.53	8.79	5.03	35.20	26.43	15.64
R&D=0	13.38	11.56	5.68	3.79	27.82	26.15	13.80
R&D=1	28.99	25.44	13.35	10.24	45.96	27.84	31.76
Innovation=0	13.53	12.99	6.30	3.31	31.21	26.81	13.18
Innovation=1	19.58	21.97	10.31	6.94	38.05	26.10	18.61
R&D=0 and Innovation=0	12.01	10.27	5.17	3.06	26.33	26.26	12.60
R&D=1 and Innovation=0	35.45	28.12	14.30	9.15	45.00	38.36	37.23
R&D=0 and Innovation=1	15.31	13.08	6.33	5.00	29.43	26.02	15.55
R&D=1 and Innovation=1	27.78	25.24	13.23	10.37	46.31	26.34	30.97
Intensity of non-university-trained employees with higher education							
All	15.77	20.49	14.22	9.54	22.25	13.76	16.17
R&D=0	14.76	19.54	11.63	8.47	22.10	13.50	15.62
R&D=1	19.68	21.20	18.00	14.04	22.48	15.04	20.98
Innovation=0	14.76	18.05	12.11	8.08	22.97	12.80	15.59
Innovation=1	16.76	21.41	15.51	11.17	21.74	14.60	16.86
R&D=0 and Innovation=0	14.18	17.84	10.72	7.80	21.73	12.58	15.42
R&D=1 and Innovation=0	23.12	19.26	21.86	14.43	26.47	17.45	22.77
R&D=0 and Innovation=1	15.57	21.56	12.79	9.58	22.49	14.56	15.91
R&D=1 and Innovation=1	19.03	21.35	17.50	13.99	21.02	14.70	20.72
Number of firms	4,825	169	341	738	725	191	2,377

Note: Used for Figure 12. Numbers are unweighted because weights in the CIS data base are developed in relation to R&D and innovation activities, not employment. The difference between the weighted and non-weighted results are of low magnitude and do not change the qualitative results. The division on firm types is based on whether firms have R&D, product innovation, process innovation, marketing innovation or organizational innovation. A firm has innovation if it has product innovation, process innovation, marketing innovation or organizational innovation. For the applied variables see note to Table 5. University-trained employees are individuals graduated from one of the 8 Danish universities; see Appendix A. Non-university-trained employees are individuals graduated from a higher education institution excluding the 8 Danish universities. Employment and education information origin from November 2013. Source: Community Innovation Survey, 2014, Highest Completed Education, 2013, Key between firms and employees, FIDA, 2013 (Statistics Denmark).

Table C7: Number of Firms that Introduces New Products, 2014

	Private sectors	High-technology manufacturing	Medium-high technology manufacturing	Other manufacturing	High-technology intensive services	Knowledge intensive financial services	Other services
New to the world	268	28	49	37	67	3	77
New to the world and R&D active	203	26	43	25	57	NA	45
New to the market	534	45	65	95	103	11	202
New to the market and R&D active	316	40	51	53	73	6	84
New to the firm	658	48	85	108	124	25	249
New to the firm and R&D active	340	39	66	61	68	13	83
All firms	1,191	88	150	190	241	41	451

Note: Used for Figure 14. Numbers are unweighted because relatively few firms have answered these questions. Based on questions related to whether newly developed products are new to the world, new to the market, or new to the firm. (Variable names: rrdin (R&D dummy), newwrd, newmkt, newfrm (product innovation).
Source: Community Innovation Survey, 2014 (Statistics Denmark).

Table C8: Sales Share of New Firm Products, 2014

Sales share for products that are	Private sectors	High-technology manufacturing	Medium-high technology manufacturing	Other manufacturing	High-technology intensive services	Knowledge intensive financial services	Other services
new to the world	0.78%	3.92%	1.45%	0.33%	2.21%	0.01%	0.33%
new to the world for R&D active firms	3.15%	6.82%	3.83%	1.58%	4.61%	0.03%	1.34%
new to the market	2.83%	7.29%	4.48%	2.68%	4.47%	1.18%	2.22%
new to the market for R&D active firms	9.23%	12.21%	9.65%	10.27%	8.20%	6.39%	9.58%
All firms with sale	4,788	158	317	724	723	193	2,389

Note: Used for Figure 15. Numbers are unweighted because relatively few firms have answered these questions. Based on questions on sales shares for newly developed products. Divided after products that are new to the world, new to the market, or new to the firm. (Variable names: rrdin (R&D dummy), turn_1, turn_2, turnin, turning (sales shares of products).
Source: Community Innovation Survey, 2014 (Statistics Denmark).

Table C9: Education Intensities after Innovation Size, University Educated to all Employees

University	World	Market	Firm	No
Product	27.0%	22.6%	20.6%	20.4%
Sales	26.8%	21.7%	19.8%	19.9%

Note: Used for Figure 16. See notes to Tables C6 and C7.
Source: Community Innovation Survey, 2014, Highest Completed Education, 2013, Key between firms and employees, FIDA, 2013 (Statistics Denmark).

Table C10: Education Intensities after Innovation Size, University Educated to Employees with Non-university Higher Education

University to non-university	World	Market	Firm	No
Product	1.37	1.29	1.21	1.12
Sales	1.37	1.22	1.20	1.07

Note: Used for Figure 17. See notes to Tables C6 and C8.
Source: Community Innovation Survey, 2014, Highest Completed Education, 2013, Key between firms and employees, FIDA, 2013 (Statistics Denmark).

5 Potential Studies

Two important results emerge from the descriptive statistics in Section 4. First, the analysis shows that university educated employees may play an important role for innovation and growth. However, it is not clear whether there is a causal effect going from higher university education intensity to productivity growth or whether the mechanism works through knowledge production, i.e., innovation and R&D. Another important aspect that is not analyzed in Section 4 is whether university education creates specific qualifications that are particular useful in knowledge production or whether university education contributes through more years of education. These are important questions for which answers would be useful.

Second, it is clear from Sections 3 and 4 that knowledge for channels of industry science linkages in Denmark is limited. In Section 4, we presented some descriptive statistics for cooperation between firms and universities. However, more knowledge for the relationship in Denmark would useful.

In the following two sub-sections we suggest two potential studies that could improve the knowledge of the importance of academic research for innovation and growth.

5.1 Potential project 1: Research-based education, innovation and firm performance

One of the most important determinants of an economy's growth is the rate of technological innovation. In an effort to spur this rate of technological innovation, significant investment is made in universities to encourage research and support the education of the workforce. This model is predicated on the idea that a university-educated workforce—one educated in an institution where research and pedagogy overlap—generates higher rates of innovation and better-quality innovation. Alternatively, investment could be channeled into teaching colleges in which the primary focus is teaching rather than research. Determining which model yields the highest return is an empirical question: Do university graduates, relative to college graduates, contribute more to innovative activity and thus firm performance?

Despite the clear importance of this question, that topic is understudied and the question remains unanswered. The topic is not understudied because it is not important but rather as a consequence of missing availability of data as firm data do not usually include education data for employees of such a detail that studies can be performed. Danish register and survey data, however, make such studies feasible.

A number of hypotheses regarding the relationship between research-based education and innovation, R&D and firm performance could be investigated by comparison of two types of firms: (F1) firms that mainly employ university graduates and (F2) firms that mainly employ teaching college graduates. The differences between F1 and F2 firms will be determined along the following margins, controlling for industry and education types: (1) R&D intensity, (2) innovation height, (3) degree of product and service imitation, (4) sales share from new products and services, and (5) degree of university collaboration. Furthermore, the relationship between firm technological efficiency and the marginal productivity of college-educated versus university-educated workers will be investigated.

Moreover, if it is found that university educated employees contributes by more than non-university educated employees, it will be analyzed whether the difference can be explained by differences in years of education or whether university education have additional contributions to innovation and growth that can be explained by average years of schooling.

The added value of a university rather than a college education as defined along myriad dimensions will be estimated in order to provide empirical guidance, for the first time in Denmark, to the optimal allocation of funds across the Danish education system.

Instrumental variable estimation will be used to deal with issues of endogeneity. So far, we have not touched upon the issue of endogeneity. If it is found that an intensive use of university-educated employees is positively related to R&D and innovation activities in firms and firm performance, it has still not been settled that the relationship is causal. It may well be the case that there are omitted variable issues; an omitted variable may, for example be an unobserved firm characteristic such as managerial ability, which drives both the hiring of university-educated employees and innovation-activities/stronger firm performance.

In the project, it will be important to try to identify exogenous variation that can explain intensive use of university-educated employees. That is, the search for good instruments for the intensity of university-educated employees are an important task. Specifically, we will focus on measures of tightness on the ("local") labor marked for firms. One possible "instrumental variable" is the distance between firm and nearest university, where the idea is that many university graduates are relatively immobile – especially in Denmark – because they are relatively old when they graduate (In this respect it should be noted that individuals graduating from university education have a median graduation age of around 28 years, see Ministry of Higher Education and Science (2013)). The hypothesis is that firms that are located far from universities will face difficulties to recruit university-educated employees. If this hypothesis holds, this may well constitute exogenous variation explaining the intensity of research-based education in firms.[11]

Danish data provides a unique opportunity for studying research-based education, non-research based education, innovation and firm performance due to high data availability. First, register data ensures matched worker-firm data covering the Danish economy over the period 1999–2013. This identification allows identification in any firm in any given year. The educational background is retrieved from Statistics Denmark's education registers, which is used to characterize the educational content of a job. The database distinguishes education groups after the length and type of the education programme (and following the Danish Education Classification system). The classification enables us to distinguish educational type as well as whether they are taught in university or in 2 or 4-year college. Finally, using the General Enterprise Statistics and the Accounts Statistics allow us to obtain information for profitability and productivity of firms.

In addition to register data on education, employment, and firm performance measures, the survey data on innovation and R&D from Statistics Denmark can be applied. These are the CIS (Community Innovation Survey) of Eurostat.

5.2 Potential project 2: Channels of industry science linkages and public policy in Denmark

Europe's lagging innovative performance has been shown to be partly related to deficiencies in industry-science links. In light of such evidence, governments have sought ways to promote greater intellectual exchange between industry and academic institutions. The general questions are if and how policy can be improved to facilitate the societal impact of public research.

Academic research is driven by individual researchers' skills, intellectual capital and curiosity. How can this innovative potential be unfolded within the framework of research set up by public policy?

The incentive effects on academic researchers of different policies such as the patent ownership rules, tax schemes for foreign researchers, or the increased reliance on private funds are not well

[11] See Card, 2001, for a similar logic used for choice of education length where individuals living closer to a college have a higher probability of taking a college-degree.

understood. This is surprising because academic researchers are the most important players in academic knowledge creation and university-industry technology transfer. These individuals perform the research that creates new discoveries, decide how and if those discoveries are publicly disclosed, and often participate in the development processes leading to commercialization

We propose to analyze the incentives and constraints researchers face, the remuneration and non-monetary benefits, such as peer recognition, and explore how these influence their research activities (publishing, patenting or starting spin-off firms). Understanding how these mechanisms work at the micro level will allow us to assess the likely impact of research policy. This research can be accomplished on the basis of uniquely detailed and comprehensive data on Danish researchers and their interactions.

The existing literature focuses on cases in which academics patent the outcome of their research or create a start-up. We saw in the literature review (section 3.4) that these are rare occurrences and are not likely to be a critical driver of private sector innovation. The evidence on the importance and effectiveness of the different channels of industry-science links is lacking for Denmark and a more comprehensive view is needed, including modes that have so far been analyzed in isolation, such as inter-sectoral mobility, academic consultancy, and co-publication activities between corporate and academic scientists. This overview is needed for a full account of the individual academic's quantitative importance in driving science-industry links and for identifying the likely determinants of their engagement. Understanding the determinants of academic mobility and other modes of interaction is also critical in obtaining unbiased assessments of the effects of different modes of person-level interactions on the performance of individual scientists, firms and universities.

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