# Three Essays on Firm Innovation

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PhD Series 34.2022

Louise Lindbjerg

# THREE ESSAYS ON FIRM INNOVATION

Department of Strategy and Innovation

**PhD Series 34.2022**

CBS COPENHAGEN BUSINESS SCHOOL
HANDELSHØJSKOLEN

# Three Essays on Firm Innovation

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Louise Lindbjerg
Copenhagen, 2022

# Summary

The ability to continuously develop and commercialize new and valuable knowledge and products is essential to firms' growth and survival. Managing innovation is an inherently challenging task as the process of generating new combinations deviates from doing business as usual. This thesis consists of three quantitative empirical investigations each dealing with strategic choices managers may make to increase innovation performance. All three chapters rely on datasets constructed using multiple data sources including the Community Innovation Survey (CIS) data, the Integrated Database for Labor Market Research (IDA), and patent data from the European Patent Office (EPO).

Chapter one draws on human capital theory to develop hypotheses on how hiring former entrepreneurs affect firm innovation measured as sales from innovation. The empirical analysis suggests that firms can increase their innovation performance by hiring entrepreneurial human capital especially when these hires occupy middle ranks in the firm hierarchy and when the quest is for innovation of more incremental rather than radical nature.

The second chapter applies theory from the economics of science literature to the setting of industrial innovation and provide the first large scale evidence on the role of physical capital in the form of research equipment for firm innovation. The findings of this paper suggest that firms tend to underinvest in research equipment, but that overinvestment also occurs which may be driven by strong complementarity between human and physical capital such that a balance in R&D expenditures allocated across the two is an important driver of innovation performance.

Finally, the third chapter looks at how pay dispersion among R&D employees may alter innovation performance, specifically, when it comes to knowledge production. Drawing on compensation theories including social comparison theory and expectancy theory, this chapter

theorizes and finds a non-linear relationship between pay inequality and knowledge production measured as patents. While pay differentials up to a certain point motivate employees as they are being rewarded for their qualities, higher levels of pay dispersion may invoke feelings of distrust and hinder collaboration.

In sum, this thesis seeks to advance theories related to knowledge production and innovation management with the aim of also providing interesting managerial insights.

# Resumé

Evnen til løbende at udvikle og kommercialisere nye og værdigskabende produkter er essentiel for virksomheders vækst og overlevelse. Innovationsledelse er udfordrende, da processen med at skabe nye kombinationer afviger fra den sædvanlige virksomhedsdrift. Denne afhandling består af tre kvantitative empiriske undersøgelser, der hver især omhandler strategiske beslutninger som ledere kan tage for at forbedre virksomhedens innovationsevne. Alle tre kapitler i afhandlingen er baseret på et datasæt som er sammensat ved brug af forskellige datakilder herunder Forskning, Udvikling og Innovationsdatabasen (FUI), den Integrerede Database for Arbejdsmarkeds-forskning (IDA) og patent data fra den europæiske patentmyndighed (EPO).

Kapitel et anvender humankapitalteori til at udvikle hypoteser omkring hvordan det at hyre tidligere entreprenører påvirker virksomhedsinnovation defineret som omsætning fra nye produkter. Resultaterne fra den empiriske analyse indikerer at virksomheder kan øge deres innovationsevne ved at hyre entreprenant humankapital. Dette gør sig særligt gældende når de tidligere entreprenører hyres til mellemlederstillinger i virksomhedens hierarki og når målet er innovation af mere inkrementel natur sammenlignet med radikal innovation.

Kapitel to tager teori fra videnskabsøkonomilitteraturen og anvender det i konteksten af industriel innovation og frembringer dermed den første empiriske dokumentation i stor skala for hvilken rolle investeringer i fysisk kapital i form af forskningsudsyr spiller for virksomheds-innovation. Resultaterne i denne forskningsartikel peger på, at virksomheder har tendens til at underinvestere i udstyr til forskning og udvikling, men at overinvestering også forekommer hvilket, formentlig skyldes den stærke komplementaritet mellem humankapital og fysisk kapital. Derfor foreslår vi, at den rette balance mellem forsknings- udviklingsudgifter på tværs af fysisk kapital og humankapital er en vigtig drivkraft for virksomheders innovationsevne.

Endelig kigger kapitel tre på hvordan lønspredningen blandt forsknings- og udviklings-medarbejdere påvirker innovationsevnen særligt når det kommer til produktionen af ny viden. Med afsæt i kompensationsteorier, herunder social sammenligningsteori og forventningsteori, teoretiserer dette kapitel, at der er en ikke-lineær sammenhæng mellem ulighed i lønninger og produktion af viden målt via patenter. Resultaterne fra den empiriske analyse understøtter teorien. Dette tyder på, at mens løndifferencer op til et vist punkt motiverer medarbejdere, da de bliver belønnet for deres evner og indsats, så frembringer store løndifferencer formentligt følelser af mistillid og øget konkurrence blandt medarbejderne, hvilket forhindrer samarbejde som er essentielt for tilvejebringelsen af ny viden.

I sin helhed, forsøger denne afhandler at avancere teorier relateret til vidensproduktion og innovationsledelse med formålet om også at bidrage med interessante ledelsesmæssige indsigter.

# Contents

# Introduction

## Motivation

Great scholars have defined innovation as new combinations (Schumpeter, 1934) yielding solutions superior to existing ones (Schumpeter, 1942), as products which are perceived to be new by the relevant unit of adoption (Zaltman et al., 1973), and as successful implementation of creative ideas (Amabile et al., 1996). From a strategic management perspective, innovation may be viewed as the process of unlocking the economic significance of knowledge by successfully introducing new solutions to the market (Grimpe & Kaiser, 2010; Leiponen & Helfat, 2010; Schubert & Tavassoli, 2020). As such, innovation plays a key role in sustained competitive advantage by building firms' knowledge bases as well as retaining and growing market shares through introduction of new products. As Dell's Entrepreneur-in-Residence, Ingrid Vanderveldt, said "If a large corporation is going to stay relevant, they have to be innovative" (Smith, 2018).

While innovation is paramount for firm growth and survival, it remains an inherently challenging task. Operating a firm is about insuring efficiency in downstream activities and consistency in upstream activities such that the firm remains profitable and customers receive the firm's offerings at the expected time and of the usual quality. Innovation, on the other hand, is fundamentally different from general firm operations in that it requires experimentation, learning and deviation from doing business as usual (Manso, 2011; March, 1991). This implies that the human and physical capital inputs for the innovation production function as well as the organizational structure surrounding the innovation process are different from those of general business conduct. This thesis investigates how firms may hire individuals with entrepreneurial human capital, balance spendings on physical capital for R&D, and incentivize R&D workers through pay structure in the quest for innovation.

The skills, knowledge, and abilities possessed by employees constitute firms' human capital (Becker, 1964) as a major source of competitive advantage (Campbell et al., 2012; Coff, 1997). Especially when it comes to innovation, input of highly skilled human capital is important. Innovation is largely driven by new combinations of knowledge and this knowledge is embedded in firms' human capital (Grant, 1996; Kogut & Zander, 1992; Tsai, 2001). Consequently, research has looked at scientist mobility and labor composition of R&D teams (Kaiser et al., 2015, 2018; Singh & Agrawal, 2011; Song et al., 2003). For instance, hiring researchers with academic (Kaiser et al., 2018) or foreign (Laursen et al., 2020) backgrounds influence the rate and direction of knowledge production in the hiring firm. While R&D workers are drivers of scientific and technological advances, a broader set of human capital needs to be considered to explain variation in firms' ability to innovate. Taking new offerings to market entails recognizing opportunities and orchestrating resources in non-routine contexts (Covin & Miles, 1999; Hitt et al., 2001; Kuratko et al., 2001; Sirmon et al., 2011). Individuals with backgrounds in entrepreneurship may be a source of entrepreneurial human capital that firms can hire to spur entrepreneurial action within established firms and increase hiring firms' ability to bring novel offerings to market.

In addition to human capital, physical capital is an essential input to the innovation process. Though knowledge is embedded in individuals, these individuals rely on corporate infrastructures to produce new knowledge. Research equipment and machinery such as microscopes, gene sequencers, and screening machines constitute the main physical capital input to the scientific process (Baruffaldi & Gaessler, 2021; Stephan & Levin, 1992; Waldinger, 2016). A central decision of R&D managers is how to allocate the R&D budget. Research has looked at the balance of spending between basic versus applied research (Czarnitzki & Thorwarth, 2012; Mansfield, 1980; Rosenberg, 1989) and internal versus external R&D (Berchicci, 2013; Cassiman & Veugelers, 2006; Grimpe & Kaiser, 2010; Hagedoorn & Wang, 2012). However, when it comes to investments in internal R&D, the role of physical capital for firm innovation is yet to be understood. Cutting edge research equipment, may not only increase efficiency of firms' scientific human capital but also improve firms' ability to retain and attract highly skilled human capital.

While knowledge resides within individuals, and thus, human capital is important for innovation, knowledge sharing between individuals and thereby the flow of knowledge across the organization, is dependent on the firm structure in which individuals are operating. Organizational structure affects employees' behavior through motivation, information processing, and coordination mechanisms (Argyres et al., 2020; Garicano, 2000; Patacconi, 2009). Firms' pay structure is closely related to organizational structure with low pay dispersion representing an egalitarian structure promoting collaboration while high pay dispersion represents a more hierarchical structure motivating individual effort (Kacperczyk & Balachandran, 2018; Yanadori & Cui, 2013). In the setting of corporate R&D, the trade-off between individual motivation and collective collaboration is especially interesting. Extant literature has documented the importance of individual top performers, also known as 'star scientists', as drivers of knowledge production (Grigoriou & Rothaermel, 2014; Kehoe & Tzabbar, 2015). On the other hand, due to the distributed nature of knowledge, collaboration among individuals is essential in creating new combinations of knowledge (Kogut & Zander, 1992; Yanadori & Cui, 2013). This tension calls for an investigation of a potential non-linear relationship between pay dispersion and knowledge production.

In sum, the motivation for the thesis is to provide large scale empirical evidence on specific inputs to the innovation process as well as the structure in which the process is embedded to advance theories within innovation management as well as the broader field of strategic management. The following sections provide an overview and summery of the three thesis chapters along with a description of the empirical foundation ending with a section on intended contributions of the thesis.

## Overview of Thesis Chapters

The first chapter of this thesis is co-authored with my former PhD colleague, Theodor Vladasel (Universitat Pompeu Fabra and Barcelona School of Economics). In this paper, we look at how firms increase their innovation performance by hiring individuals with entrepreneurial human capital. We are currently revising the paper for first-round R&R at the Strategic Management Journal. The second chapter is co-authored with Christoph Grimpe (Copenhagen Business School) and Markus Simeth (Copenhagen Business School). We investigate the role of research equipment for firm innovation and propose that cutting edge research equipment not only increases the efficiency of R&D workers but also improves firms' ability to attract and retain highly skilled human capital. The third chapter is a single-authored paper in which I uncover an inverted u-shaped relationship between horizontal pay dispersion among R&D employees and technological knowledge production. I explore mechanisms of social comparison and labor market dynamism. All three chapters develop theoretical predictions which are examined by running regression analyses on comprehensive datasets.

Figure 1: **Overview of thesis chapters**

| Paper Title | Research question | Dependent varible | Main finding |
|---|---|---|---|
| **Chapter 1** | | | |
| Hiring Entrepreneurs for Innovation | Can established firms improve their innovation performance by hiring former entrepreneurs? | Sales from innovation | Firms who hire entrepreneurs have higher innovation output |
| **Chapter 2** | | | |
| The Role of Research Equipment for Firm Innovation | What is the role of research equipment for firm innovation? | Sales from innovation | Firms who invest relatively more in R&D equipment have higher and more novel innovation output |
| **Chapter 3** | | | |
| The Non-linear Relationship between Horizontal Pay Dispersion and Technological Knowledge Production | How does pay dispersion among R&D employees influence knowledge production in firms? | Patents | High levels of pay dispersion is negative for knowledge production, but many firms may benefit from increased pay inequality |

# Chapter 1: Hiring Entrepreneurs for Innovation

The first chapter of this thesis focuses on a specific type of human capital which may improve firms' ability to take innovation to market. Human capital is key to firm performance and sustained competitive advantage (Campbell et al., 2012; Coff, 1997). The hiring-for-innovation literature highlights the importance of continuous inflows of different types of human capital for firms to access a diverse set of knowledge, skills, and experiences to fuel the innovation process (Almeida & Kogut, 1999; Rosenkopf & Almeida, 2003). Technical human capital improves firms' invention outcomes (Kehoe & Tzabbar, 2015; Singh & Agrawal, 2011; Song et al., 2003) but does not guarantee successful implementation. Innovation may require distinct skills in bringing new ideas to market. We argue that former founders are a unique source of entrepreneurial human capital especially suited to create and exploit market gaps by acquiring and mobilizing resources, so entrepreneurial human capital enhances innovation in established organizations.

Combining register and Community Innovation Survey data from Denmark, we show that entrepreneur hires are associated with higher sales from new products and services. This result is driven by founder hires in middle management, a hierarchical position where broader decision rights and resource access increase effectiveness of entrepreneurial human capital. Founder hires are more tightly linked to innovation new to the firm or market, rather than world, consistent with our prediction that former founders apply generalist knowledge to spot existing opportunities to bring incremental improvements to market, but do not necessarily generate radical innovation which is more tied to specialized knowledge. Our findings suggest that entrepreneurial human capital may help firms appropriate a larger share of the value their knowledge generates. We investigate a series of alternative explanations related to managerial skills, technical knowledge, and acqui-hires. As one would expect, entrepreneur hires do not increase innovation in very large firms where one or few hires are unlikely to affect firm outcomes.

# Chapter 2: The Role of Research Equipment for Firm Innovation

Chapter two looks at physical capital which alongside human capital is the major input to the innovation process. Research has rightfully paid substantial attention to human capital given the importance of individuals' knowledge and skills for firms' ability to generate new combinations (Grant, 1996; Kogut & Zander, 1992). But corporate scientists need research equipment and machinery to perform R&D tasks and ultimately generate innovation. The role of this specific type of capital for innovation is largely unknown. The economics of science literature has shown that research equipment affects productivity and trajectories of academic scientists (Baruffaldi & Gaessler, 2021; Furman & Teodoridis, 2020; Waldinger, 2016). Similar predictions can be made in the context of firm innovation. For corporate R&D managers a key decision is how to allocate the R&D budget, for instance, across internal and external R&D (Berchicci, 2013; Cassiman & Veugelers, 2006; Grimpe & Kaiser, 2010; Hagedoorn & Wang, 2012). When it comes to internal R&D, this study is the first to investigate the balance between human capital and physical capital.

Using Danish Community Innovation Survey and register data, we show that while over-investment in R&D equipment is associated with declining returns for innovation in terms of sales from new products, most firms invest below the infliction point. In line with arguments from the economics of science literature of changed trajectories, we find that R&D equipment is especially important for radical innovation. We argue that research equipment not only increases efficiency of firms' scientific human capital through optimization and redirection of attention, but also increases firms' ability to retain and attract highly skilled human capital with the prospect of working with cutting edge research tools. Results from firm fixed effects estimations uncover that upon investing in physical capital, firms' R&D teams become more PhD-researcher intensive and investments in research equipment appear especially important for firms in high-employee-turnover sectors and for firms who are industry laggards.

# Chapter 3: The Non-linear Relationship between Horizontal Pay Dispersion and Technological Knowledge Production

While chapter one and two look at sales from new offerings as an output of the innovation process, the third chapter looks at firms' ability to create new technological knowledge in the form of patents which is an important antecedent for firm innovation (Trajtenberg, 1990). Creating inventions is a collective effort of individuals bringing together knowledge (Haas & Ham, 2015; Kogut & Zander, 1992). At the same time, inventive capability is dependent on the performance of highly skilled individuals such as 'star scientists' (Grigoriou & Rothaermel, 2014; Kehoe & Tzabbar, 2015). Firms' pay structure alter individual and collective behavior through motivation and coordination mechanisms (Balkin et al., 2000; Cui et al., 2019; Lerner & Wulf, 2007), and thus, designing a pay structure that balances the need to incentivize both individual effort such as hard work and collective effort such as knowledge sharing is a challenge for decision makers.

In this paper, I replicate the finding by Yanadori & Cui (2013) that high horizontal pay dispersion among R&D workers, hence, large pay inequality among employees at the same organizational rank, is negatively associated with knowledge production. However, when firm fixed effects are considered, the effect becomes positive. I show that this inconsistency is due to a non-linear relationship between pay dispersion measured by the Gini coefficient of R&D employees' salaries and technological knowledge production measured as number of new patent filings. Furthermore, pay dispersion appear only to alter knowledge production in single-establishment settings indicating that social comparison is a driving mechanism, and in settings with a dynamic labor market, i.e., large supply of both R&D employees and R&D intensive firms. These results suggest that the negative externality of pay dispersion kicks in at a later stage and that innovative firms may benefit from a more hierarchical pay structure than what we have thought, traditionally.

# Empirical Context

As this thesis is based on comprehensive datasets using multiple different data sources at various levels of analysis, the following section provides a detailed description along with an overview of the empirical foundation for my doctorial research. All three chapters of the thesis take place in the empirical setting of Denmark. The richness of data made available by the Danish national statistics bureau, Statistics Denmark, allow me to analyze innovation related outcomes as a function of employees' career histories, investments into R&D, and pay structure based on individual salaries. The main data source covers the universe of Danish firms and individuals such that I can test theoretical predictions based on a broader set of firms especially when it comes to firm size, than what is usually available in, for example, US data. This also enables a host of interesting heterogeneity analyses and remedies for endogeneity concerns.

This setting is attractive for multiple reasons. Driven by the flexicurity model, Denmark has a vibrant labor market with frequent moves between occupations making it a good context for studying inflows of human capital to firms as we do in chapter one where we look at hiring former entrepreneurs for innovation. Compared with other OECD countries, Denmark has a high rate of entrepreneurship potentially driven by the ability to experiment with different career spells due the social security net. Hence, we have a critical mass of entrepreneurs. The Danish economy is to a large extent driven by export of R&D intensive products. The presence of globally innovative companies provides a large and representative sample for studying the role of research equipment for firm innovation as per chapter two. Finally, Danish employers report the exact salaries of each individual employees to the central tax authority such that individual salaries, and thus, pay structure can be tracked accurately. The employer-employee linked data enables tracking employees' education as well as functional and hierarchical position in the firm providing unique benefits for investigating the relationship between pay dispersion and knowledge production.

# Data

The empirical foundation of this thesis is a number of datasets that I have constructed using multiple sources of data at multiple levels of observation. The main data source is the Integrated Database for Labor Market Research (IDA) made available by Statistics Denmark. The database in internationally renowned for the ability to reliably track employer-employee linked information over time and it has been used in numerous papers published in top outlets (for instance, Dahl & Sorenson, 2012; Kaiser et al., 2018; Rocha & van Praag, 2020). The IDA database has three units of observation; individual level, establishment level, and firm level. Individuals are uniquely identified (though strictly anonymized) through social security numbers.

In building a dataset, I start by identifying the relevant employer-employee links in the IDA data. An individual can have multiple occupations, and thereby, multiple employer-employee links within a given year. For my analyses, I only consider employees having their main occupation with a given firm as identified by the occupation through which the individual pays its main tax. This choice is made for two reasons. First, I assume that only employees who have their main occupation in the firm are embedded enough in the firm to be of strategic importance and to contribute to firms' innovation activities. Second, as an individual can only have one main occupation within the year, individual observations become unique making subsequent mergers and aggregations much less error prone. I link unique individuals from the IDA dataset to multiple data sources. The UDDA dataset provides information on highest completed education which I use together with International Standard Classification of Occupations (ISCO) codes from the AKM dataset to identify R&D workers and university graduates along with their hierarchical position within the focal firm. I link to the general population dataset, BEF, to obtain employees' ages while the IDA dataset contain information on employees' tenure within the firm. After merging the individual-level datasets, I generate the variables of interest.

For chapter one, the main challenge is to identify new ventures and their founders. To identify new ventures, I link IDA data to the general firm database, FIRM, to obtain the year a firm is established as a legal entity. Venture founders are identified using a combination of salary data from IDA and occupation data from AKM following the approach of Sørensen (2007). Though used in all three chapters, an important measure for chapter two is R&D employees identified as individuals with higher education in STEM fields occupying a knowledge intensive position in the focal firm (Kaiser et al., 2015, 2018). Individual-level data is aggregated to the level of the firm by counting number of, for example, former entrepreneurs or R&D employees in the firm and in some cases dividing by empirical firm size to obtain shares. Empirical firm size is always measured using only employees having their main occupation with the firm. For chapter three, the individual-to-firm level aggregation is done by using individual employees' salaries as input to a Gini coefficient function calculating firm-level pay dispersion.

Figure 2: **Overview of datasets used in this thesis**

| | Description | Coverage | Unique obs. | |
|---|---|---|---|---|
| CIS | Commnity Innovation Survey | Survey sample | ~ 4,500 | Firm level |
| EPO | Patents | Patent active firms | ~ 1,400 | |
| FIRM | General firm data | All firms | ~ 700,000 | |
| IDAN | Labor market - employments | Active firms | ~ 300,000 | |
| IDAS | Labor market - establishments | Active workplaces | ~ 200,000 | Establishment level |
| IDAN | Labor market - employments | Employees | ~ 3,000,000 | Individual level |
| UDDA | Education | All individuals | ~ 5,000,000 | |
| AKM | Occupation | All individuals | ~ 5,000,000 | |
| BEF | General individual data | All individuals | ~ 5,000,000 | |

Note: All firms include holding companies and firms no longer active
Note: Not all firms have establishments, e.g. solo ventures

In IDA, a firm is uniquely identified as a tax paying entity. The IDA database includes a sub-dataset identifying physical workplaces owned by a firm. A physical workplace, or establishment, is tracked over time even when the ownership of the establishment changes. I rely on this feature to identify acqui-hires which are an important alternative explanation for our results in chapter one. For chapter three, count of establishments within a firm is used as a control as well as a sample split.

At the firm-level, the IDA data is linked to the FUI dataset containing Community Innovation Survey (CIS) data providing the main measure of innovation output used in chapter one and two. Following previous innovation research (Cassiman & Veugelers, 2006; Klingebiel & Rammer, 2014; Laursen & Salter, 2006; Leiponen & Helfat, 2010), innovation is measured as share of sales from innovation reported yearly by R&D managers or equivalent at the central authority for business registration and declaration. For robustness, total sales from innovation is used by multiplying the share reported in CIS with firm sales from the FIRM database to overcome shortcomings of having a dependent variable with a denominator.

As the collaboration mechanisms theorized in chapter three speaks more directly to knowledge production, patents are used as another classical measure of firm innovation (Argyres & Silverman, 2004; Cui et al., 2019; Kaiser et al., 2015). The data from the European Patent Office (EPO) is linked to unique firm identifiers by Statistics Denmark to ensure anonymity.

From the FIRM dataset, I obtain firm-level controls such as sales from export, net investments, and physical capital. All firm-level merges are done using a unique identifier of the firm as a legal tax paying entity. Due to the implementation of a new firm key identifier in the IDA data in 2008, the new firm identifier can be linked to IDA data going back to 1999 using keys from the FIDA and FIDL datasets. I have done substantial checks for consistency across this cut-off point.

## Sampling

In chapter one, the analysis sample includes established firms as we are interested in whether established firms can improve their innovation performance by hiring former founders of startups. We restrict the sample to firms that are more than five years old and have more than twenty-five employees to ensure that we do not count startups and very small firms which may be equally entrepreneurial. For chapter two, the sample includes firms with R&D expenditures because the main independent variable is share of R&D expenditures spend on research equipment and machinery. Both chapters are restricted to firms who participate in the Community Innovation Survey which is around 4,500 firms per year with higher sampling intensity for large R&D intensive firms and a rolling panel of about five hundred firms. Chapter three relies on a sample of firms with more than five R&D employees at each relevant firm layer (medium and high knowledge ranks) making this sample the most R&D intensive of the three chapters. To preserve a large and balanced sample R&D expenditures, a CIS variable, is not included in main estimations but in robustness checks. All analyses are run at different sample cuts to check that results are not sensitive to cut-off points, identify boundary conditions, and increase credibility by showing that results do not hold in settings where, theoretically, we would expect them not to.

Figure 3: **Overview of sample selection**

| | Chapter 1 | Chapter 2 | Chapter 3 | |
|---|---|---|---|---|
| Sample Filters | *Established firms*<br>Observed in CIS<br>> 5 years old<br>> 25 employees | *R&D active firms*<br>Observed in CIS<br>R&D expenditures | *R&D intensive firms*<br>> 5 R&D employees at each relevant firm layer | **Firm level** |
| Individuals with primary occupation in the focal firm | | | | **Individual level** |
| Firm-year obs. | 20,271 | 6,534 | 4,151 | |
| Unique obs. | 3,846 | 1,416 | 838 | |

## Contributions

This thesis intents to make contributions to the field of innovation management and the broader field of strategic management. All three chapters make distinct contributions to human capital literature (Becker, 1964; Campbell et al., 2012; Coff, 1997) and innovation literature (Burns & Stalker, 1994; Ederer & Manso, 2013; Grigoriou & Rothaermel, 2014; Kaiser et al., 2018; Laursen & Salter, 2006; Schubert & Tavassoli, 2020; Yanadori & Cui, 2013; Zaltman et al., 1973).

By bridging hiring-for-innovation and entrepreneurship literature, chapter one points to entrepreneurial human capital as an overlooked and potentially valuable source of firm innovation. A second contribution of this chapter is to the literature on returns-to-entrepreneurship (Campbell, 2013; Manso, 2016) which usually considers induvial outcomes such as pay and career trajectories of former entrepreneurs. Our results suggest that returns to entrepreneurship may be undervalued when these are viewed at the individual level. Entrepreneurship experience may foster a unique source of human capital valuable to innovative firms.

Chapter two complements studies on human capital by showing that physical capital in the form of research equipment and machinery is important for firms' human capital to reach its full potential. We argue that research equipment also plays a role in the composition of the human capital by attracting and retaining highly skilled human capital. We apply theory from the economics of science literature (Ding et al., 2010; Stephan, 1996; Waldinger, 2016) to the setting of industrial innovation and provide an important empirical contribution by, for the first time, showing large-scale empirical evidence of the role of physical capital for firm innovation. We contribute to the innovation literature by showing that internal R&D expenditures may not only be a means for firms to increase innovation potential (Berchicci, 2013; Hagedoorn & Wang, 2012) and absorptive capacity (Cohen & Levinthal, 1990; Fabrizio, 2009), but may also be a strategic tool for firms who have difficulty attracting and retaining highly skilled human capital.

Chapter three draws on pay dispersion (Bloom, 1999; Bloom & Michel, 2002; Fredrickson et al., 2010) and organizational structure literature (Argyres & Silverman, 2004; Burns & Stalker, 1994; Garicano, 2000) to provide empirical evidence on how it is not only human capital that determines knowledge production but also the firm structure in which the human capital operates. This paper contributes to the literature on pay dispersion and incentives for innovation (Cui et al., 2019; Ederer & Manso, 2013; Manso, 2011, 2017; Yanadori & Cui, 2013) buy showing that predicted negative effects of pay inequality on innovation kick in at high levels of dispersion and only in certain settings thereby suggesting boundary conditions for these theories.

An important limitation of the thesis is the lack of ability to draw causal conclusions. When it comes to identifying innovation performance as a function of firm inputs and structure, several sources of endogeneity cannot be fully addressed. In chapter two, we are challenged by the double-sided matching in the labor market, i.e., which entrepreneurs choose to leave entrepreneurship and join an established firm and which firms hire entrepreneurs? This endogenous matching could be a driver of our results. For chapter two, a similar concern, although single-sided, arises in terms of who are the firms who choose to invest in research equipment and machinery. It may be those who already anticipate to innovate. In chapter three, pay dispersion might be an artefact of another organizational practices which might explain my results. These concerns are addressed using firm fixed effects, careful selection of controls, heterogeneity analyses, past performance indicators, and detailed descriptive statistics. At this point, however, the results of this thesis shall not be interpreted as causal but as interesting theoretical ideas which are supported by associations in a comprehensive dataset. As the research papers of the thesis continue to advance, I aim to address endogeneity concerns more explicitly through instrumental variables and matching approaches. I hope this research will spur future endeavors into further understanding the role of entrepreneurial human capital, physical capital, and pay structure for knowledge production and innovation.

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# Chapter 1: **Hiring Entrepreneurs for Innovation**

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## 1.1 Introduction

Human capital contributes to innovation and competitive advantage by allowing organizations to exploit knowledge and develop capabilities (Coff, 1997; Campbell et al., 2012a). Human capital is often acquired externally, with the hiring-for-innovation literature highlighting firms' reliance on inflows of knowledge, skills, and experiences from new hires in their efforts to generate and market novel ideas (Almeida and Kogut, 1999; Rosenkopf and Almeida, 2003). Recruiting highly skilled inventors boosts firms' patenting output and affording them insight into new technical domains (Song et al., 2003; Tzabbar, 2009; Singh and Agrawal, 2011; Kaiser et al., 2018). Yet, for this knowledge to drive profits and performance, established organizations must create and exploit novel business opportunities (Covin and Miles, 1999; Hitt et al., 2001; Teece, 2016). Such functions require a distinct human capital profile centered on new idea execution, combining broad sets of knowledge into novel offerings. We argue that former founders are endowed with execution skills and that hiring individuals with entrepreneurial human capital benefits firms' innovation. Entrepreneur hires, especially when paired with the relevant decision rights, provide an additional path for incumbents to exploit their knowledge internally, appropriating a larger share of the value created through innovation.

Innate preference, skill, and judgment differences relative to employees predispose entrepreneurs to pursuing new ventures; moreover, start-ups expose individuals to a dynamic, uncertain environment and a steep learning curve with regards to both organizational practices and competitive landscape insight. As founders, entrepreneurs deepen their generalist expertise in social and material resource acquisition and mobilization across functional domains and audiences, such as customers, competitors, or suppliers (Alvarez and Busenitz, 2001; Lazear, 2005; Elfenbein et al., 2010; Campbell, 2013; Foss and Klein, 2012; Distel et al., 2019; Faleye et al., 2020). Entrepreneurs thus possess execution skills uniquely suited for taking new ideas to market. We propose that execution skills transcend the start-up context and can be deployed by established firms seeking to bring new products and services to market. This process requires connecting an organization's knowledge with market needs by assembling the requisite internal and external resources, such that entrepreneur hires increase firms' sales from innovation.

The nature of execution skills holds additional implications for how entrepreneur hires affect innovation. Central positions of authority and broader decision rights facilitate the exercise of judgment over what resources to acquire and mobilize in developing new ideas, while product development and market insight help former founders select more profitable projects (Burgelman, 1991; Wooldridge et al., 2008; Foss and Klein, 2012). We thus posit that founder hires in middle management roles have stronger effects on innovation than hires in other ranks. Moreover, radical innovation depends heavily on specialized technical investments and human capital, while incremental innovation benefits from broad search strategies emphasizing customers and competitors (Gatignon et al., 2002; Köhler et al., 2012). Former founders' generalist skill profile favors the pursuit of otherwise difficult to spot marginal improvements, so we propose that entrepreneur hires are more tightly linked to incremental rather than radical innovation.

To test our theory, we combine matched employer-employee administrative and Community Innovation Survey data for Denmark for the years 2007-2016, allowing us to analyze firm-level innovation outcomes, while capturing employees' career history in detail. Empirically, we focus on new entrepreneur hires' effect on firms' share of sales from innovation. To alleviate worker firm matching concerns, we use firm fixed effects models netting out time-invariant traits and control for multiple lags of sales growth and investment intensity to address time-variant demand for execution skills. As our theory predicts, the positive association between entrepreneur hires and innovation sales is driven by hires in middle management; founder hires are also strongly related to less radical innovation, new to the firm or market, but not the world. Moreover, we rule out explanations based on technical or managerial skills, provide descriptive statistics that alleviate selection concerns, and find that execution skills are subject to depreciation, implying that regular inflows of former founders may be required for sustained innovation.

This paper makes two key contributions to strategic management. We bridge entrepreneurship and hiring-for-innovation research to explain how firms can gain capabilities for boosting innovation through a novel human capital channel (Alvarez and Busenitz, 2001; Teece, 2016). Beyond acquiring technical human capital directly involved in producing inventions (Song et al., 2003; Tzabbar, 2009; Singh and Agrawal, 2011; Kaiser et al., 2018), firms must obtain business development capabilities, so hiring for innovation must account for execution skills. Hiring entrepreneurs for their generalist ability to marshal resources to exploit existing knowledge and bring new offerings to market offers a path for developing these competences, allowing firms to retain more of the value created, rather than cede it to competitors. Moreover, companies hiring former entrepreneurs in middle management roles may be especially well placed for developing sustained competitive advantage, as entrepreneurial human capital reaches its productive potential when accompanied by the relevant decision rights over resource allocation (Teece, 1996; Foss et al., 2015). Execution skills' contribution to firm performance and their interaction with organizational design and other types of human capital can serve as an avenue for further studies of innovation, learning by hiring, and strategic entrepreneurship.

Building on studies of selection (Lazear, 2005; Roach and Sauermann, 2015; Vladasel et al., 2021) and learning (Elfenbein et al., 2010; Eesley and Roberts, 2012; Parker, 2013), we add to the growing literature on returns to entrepreneurial experience (Campbell, 2013; Manso, 2016), proposing that former founders are distinctly endowed with execution skills. These skills cover the entire business development process, centering on forming novel market opportunities for exploiting firm knowledge through resource configuration. Closely related to entrepreneurial top managers and directors' resource reallocation ability (Distel et al., 2019; Faleye et al., 2020) and entrepreneurial judgment (Foss and Klein, 2012), new idea execution skills span all stages of venture creation, are transferable across contexts, and have clear testable implications. Established firms' innovation benefits from such skills, providing an explanation for recent studies finding positive earnings effects for entrepreneurs returning to paid employment, especially in knowledge intensive sectors (Campbell, 2013; Luzzi and Sasson, 2016; Manso, 2016). By making precise wherein the portability of entrepreneurial human capital lies, we offer a starting point for investigating how former founders are integrated into established firms and how their skills are deployed and rewarded across domains. Our work highlights that monetary returns to entrepreneurship also accrue to existing organizations: building on a large body of work assessing entrepreneurs' careers, we add to a burgeoning literature on consequences for the firms hiring them (Distel et al., 2019; Faleye et al., 2020; Braunerhjelm and Lappi, 2021), examining the nature of their human capital and finding positive effects on innovation.

## 1.2 Theory and Hypothesis

We develop a theoretical reasoning predicting how innovation benefits from hiring entrepreneurs. We outline how founders' human capital is distinct from that of employees, positing that they are endowed with superior execution skills. We then propose that entrepreneur hires help firms gain capabilities in bringing new products and services to market. Finally, we reason that execution skills are most effective when entrepreneurs are hired in middle management ranks and are particularly valuable for incremental innovation.

### 1.2.1 Entrepreneurial Human Capital

Entrepreneurs differ from workers in both their pre-entry traits and the skills acquired through their business (Elfenbein et al., 2010; Eesley and Roberts, 2012).[1] On average, individuals who

[1] Entrepreneurs are theoretically and empirically distinct from the self-employed, given the different organizational forms pursued and tasks performed, partially due to entrepreneurial selection from different parts of the ability distribution (Åstebro et al., 2011; Levine and Rubinstein, 2017; Vladasel et al., 2021).

become entrepreneurs have higher non-routine (non)cognitive ability, higher social skills, generalist skills, higher risk and loss tolerance, higher (over)confidence, as well as preferences for autonomy, commercialization, and managerial activities.[2] These traits make entrepreneurs better predisposed to take on new venture development projects, from initially spotting opportunities to finally bringing new ideas to market, relative to other workers.

Founding a firm is an intense experience in developing and executing a business idea. Entrepreneurs perform varied functions inside start-ups, allowing them to develop skills regardless of the firm's ultimate success or failure (Minniti and Bygrave, 2001). In highly uncertain environments, founders exercise judgment over how to deploy heterogeneous resources to achieve various outcomes (Foss and Klein, 2012): they plan, experiment with, and execute strategy (Camuffo et al., 2020; Ching et al., 2019); acquire and mobilize the required human, social, and financial capital resources (Davidsson and Honig, 2003; Baker and Nelson, 2005; Hsu, 2007; Zott and Huy, 2007; Zhang, 2011); and lead and manage the start-up (Lounsbury and Glynn, 2001; Hmieleski and Ensley, 2007; Eesley and Roberts, 2012). Entrepreneurs thus gain expertise in many functional areas and strengthen their generalist profile, helping them develop unique venture development skills due to an ability to recombine broad sets of knowledge for the execution of new ideas (Elfenbein et al., 2010; Campbell, 2013). Moreover, beyond ex ante higher alertness, practical experience and contact with clients or competitors improve founders' ability to conceive projects that deploy resources to potentially highly profitable new uses (Baron and Ensley, 2006; Ucbasaran et al., 2009; Faleye et al., 2020).

Built through a dynamic career trajectory, entrepreneurs' human capital is distinct from employees', especially in their higher capacity to create strategic opportunities, assemble and configure heterogeneous resources, as well as execute relevant strategy (Alvarez and Busenitz,

[2] Among others, Busenitz and Barney (1997), Lazear (2005), Hartog et al. (2010), Åstebro et al. (2011), Roach and Sauermann (2015), Koudstaal et al. (2016), Levine and Rubinstein (2017), Vladasel et al. (2021).

2001; Foss and Klein, 2012). Entrepreneurs thus possess superior execution skills in bringing new ideas to market, enjoying advantages over non-entrepreneurs at all venture development stages, especially in market-facing ones. Distinct from pure technical or routine managerial skills, this knowledge-intensive occupational human capital (Mayer et al., 2012) facilitates successful future entrepreneurial endeavors, as research on serial entrepreneurs' improved performance shows (Gompers et al., 2010; Eesley and Roberts, 2012; Parker, 2013).

New ventures are not alone in rewarding former entrepreneurs' execution skills. While earlier studies uncover negative returns to entrepreneurship experience in paid employment (Hamilton, 2000; Bruce and Schuetze, 2004; Baptista et al., 2012), recent work paints a positive picture. Entrepreneurs receive a premium upon returning to established firms (Campbell, 2013; Manso, 2016), especially in innovative sectors (Luzzi and Sasson, 2016) or if they have industry experience (Kaiser and Malchow-Møller, 2011), are more likely to reach managerial positions (Baptista et al., 2012; Mérida and Rocha, 2021), and earn higher executive pay (Mérida, 2019).[3] That incumbent firms reward entrepreneurial human capital provides initial evidence that founders' skills are valuable across contexts. We now turn to a theoretical analysis of how entrepreneur hires' execution skills affect firm innovation.

### 1.2.2 Entrepreneur Hires and Firm Innovation

Entrepreneurial action inside established organizations has been proposed as a complement to traditional inventive activities, allowing for the economic exploitation of technical and scientific advances (Schumpeter, 1934; Arrow, 1962; Nelson and Winter, 1982; Covin and Miles, 1999; Hitt et al., 2001). But while scholars have paid substantial attention to the effect of knowledge worker hires on firms' development of inventive capabilities, i.e. patenting activities, we know

[3] Firms may initially offer former entrepreneurs lower wages due to uncertainty about their ability (Mahieu et al., 2021), but these wages recover and surpass those of workers in the long run (Mérida and Rocha, 2021).

far less about how organizations recruit human capital for transforming inventions into innovations that can be successfully commercialized, i.e. revenue from innovation.

The idea that organizations build, broaden, or deepen capabilities by hiring workers with different knowledge, perspectives, or skills is hardly novel (March, 1991; Rao and Drazin, 2002; Song et al., 2003; Hatch and Dyer, 2004; Lacetera et al., 2004; Jain, 2016; Wang and Zatzick, 2019). New inventor hires affect the quantity, quality, and direction of hiring firms' inventive activities: the knowledge new hires bring from previous contexts such as universities or other innovative firms is reflected in the hiring firm's patents (Almeida and Kogut, 1999; Rosenkopf and Almeida, 2003; Song et al., 2003; Tzabbar, 2009; Palomeras and Melero, 2010; Singh and Agrawal, 2011; Herstad et al., 2015; Kaiser et al., 2015, 2018).[4] Nonetheless, while recruiting inventors spurs patenting, it does not guarantee commercial success.

What human capital do established firms need to hire in order to innovate? Bringing new ideas to market requires firms to undertake entrepreneurial action, characterized by market opportunity creation and resource orchestration in non-standard contexts (Covin and Miles, 1999; Hitt et al., 2001; Kuratko et al., 2001; Sirmon et al., 2011), thus extending further than technical or managerial skills. Entrepreneurial action, as a counterpart to invention, requires employees to tolerate uncertainty and apply their knowledge to commercial ends as they execute strategy with the aim of placing firms on a path to competitive advantage (Stevenson and Jarillo, 1990; Covin and Miles, 1999; Antoncic and Hisrich, 2001; Butler, 2017). These requirements match the execution skills we describe, implying that more generalist former founders have an advantage in marshaling requisite resources for bringing new offerings to market. For instance, multinational companies exhibit larger host country sales when subsidiary managers have entrepreneurial experience, due to their resource allocation skills and enhanced local market knowledge (Distel

[4] Firms also hire strategic human capital in advocacy or exports in order to develop stakeholder or foreign market knowledge, respectively (Grimpe et al., 2019; Guri et al., 2019).

et al., 2019), while entrepreneurs on the board are positively linked to R&D investments and firm market value (Faleye et al., 2020); more generally, founder hires can help increase firms' long-run productivity (Braunerhjelm and Lappi, 2021).

We thus conceptualize execution skills as a unique multidimensional bundle of traits, abilities, and experiences that allows former founders to successfully pursue new ventures conducive to innovation in established firms. Due to superior competitive landscape insight, entrepreneurs are on average better than other employees at recognizing the commercial potential of existing firm knowledge and devising the appropriate market strategies for realizing opportunities. In addition, introducing new products and services is an uncertain, non-routine endeavor that former founders are better equipped to navigate. Entrepreneurs' higher social skills are useful for assembling the internal and external resources needed for project completion, including financial support and buy-in from employees, leadership, and external stakeholders. Former founders accomplish this broad array of tasks more easily than employees due to their generalist skills and varied functional expertise.[5] Overall, we propose that:

**Hypothesis 1** *Hires with founder experience are positively associated with sales from innovation in established firms.*

### 1.2.3 Entrepreneur Hires in Middle Management

Firms' ability to innovate depends not only on human capital, but also on organizational design (Miller, 1983; Teece, 1996; Dess et al., 1999; Foss et al., 2015). By influencing the flow of information and collaboration across the firm through coordination and motivation mechanisms, organizational design may facilitate or hinder workers' ability to exercise their skills. Thus, an important decision firms face is not just whether to hire former founders, but what level of

[5] Despite concerns that entrepreneurs avoid larger, more bureaucratic organizations (Corbett and Hmieleski, 2007; Sørensen, 2007; Butler, 2017), such firms could remain attractive when higher levels of material and social resources facilitate the deployment of execution skills relative to more constrained environments.

authority and responsibility to entrust them with (Foss and Klein, 2012). Distel et al. (2019) and Faleye et al. (2020) show that entrepreneurs in top management teams or on the board of directors can direct firm strategy and investments, with positive performance effects. While few former founders transition to executive positions quickly, many return to middle management (Baptista et al., 2012), where they enjoy the autonomy often associated with entrepreneurial roles. Moreover, the nature of execution skills and the innovation process suggest that entrepreneur hires are particularly important for bringing new ideas to market when paired with the decision rights afforded to middle managers.

Whereas top managers outline the broad contours of strategy, implementation and execution are usually delegated to middle managers (Kanter, 1982; Burgelman, 1983b; Wooldridge et al., 2008), whose involvement and engagement are positively linked to firm performance (Wooldridge and Floyd, 1990; Huy, 2001; Mollick, 2012). Middle managers constitute a critical organizational design element, performing an information processing function (Garicano, 2000; Colombo and Grilli, 2013; Wooldridge et al., 2008). Put differently, they represent agents of selection inside the firm, picking ideas worth championing and acquiring the requisite resources for their execution (Burgelman, 1983a, 1991; Mollick, 2012). Middle managers' capacity to command upwards and downwards influence is driven by their ability to span boundaries across firm layers, manage emotions and navigate organizational culture, and clearly communicate organizational purpose (Floyd and Wooldridge, 1997; Huy, 2002, 2011; Rouleau and Balogun, 2011; Ahearne et al., 2014; Guo et al., 2017; Gartenberg et al., 2019). Unsurprisingly, middle managers play a key role in firms' entrepreneurial behavior and innovation (Burgelman, 1983a). [6]

[6] Selective intervention by senior management retains an important role in opportunity formation (i.e. new product and service introduction), amplifying the positive effects of bottom-up initiative (Barney et al., 2018).

Due to their central position in the flow of information, configuration of resources, and exercise of authority, middle managers' involvement in all stages of venture development connects naturally with execution skills. New entrepreneur hires generally link firms' existing technical knowledge with unaddressed market needs, but non-managerial roles rarely confer the authority required to assemble the requisite resources for pursuing innovation; conversely, top managers dispose of stronger decision rights and guide strategy but may not command full knowledge of firms' technical assets and may be unable to connect them with market gaps (Stevenson and Jarillo, 1990). Middle management roles offer a practical compromise between these extremes, allowing former founders to provide valuable inputs across all stages of new ventures, not just in limited phases of new business development (Burgelman, 1983a).

To begin with, superior market insight and easier access to firms' technical knowledge help new entrepreneur hires in middle management act as effective agents of selection; that is, they discern the value of different ideas, authorize subsequent development, and champion the projects they deem most market-ready or profitable.[7] Central positions in information and resource flows then facilitate the acquisition of financial support and buy-in for selected ideas by allowing their access to gatekeepers and decision makers at both lower and higher levels of hierarchy, as well as external stakeholders; at this stage, execution skills' social dimension likely plays a vital role. Middle managers' support for entrepreneurial action is also strongly associated with firms' implementation of innovative ideas (Kuratko et al., 2005; Hornsby et al., 2009), so hiring former founders in such positions may disseminate and foster a broader entrepreneurial culture throughout the organization. These arguments therefore imply that:

**Hypothesis 2** *The positive relationship between hires with founder experience and sales from innovation is stronger for entrepreneur hires in middle management positions.*

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[7] This logic applies to both selecting in valuable opportunities and selecting out poor projects (Lerner and Malmendier, 2013), improving firms' overall innovation portfolio (Klingebiel and Rammer, 2014).

### 1.2.4 Entrepreneur Hires and Incremental Innovation

The nature of entrepreneurial human capital holds implications for the type of innovation firms can introduce and appropriate value from. Researchers and practitioners commonly distinguish two broad categories: incremental innovation 'involves refining, improving, and exploiting an existing technical trajectory', whereas radical innovation 'disrupts an existing technological trajectory' (Gatignon et al., 2002). We argue new entrepreneur hires help discover marginal improvements to firms' under-utilized knowledge and have a larger effect on incremental, rather than radical innovation, echoing the notion that 'exploitation includes such things as refinement, choice, production, efficiency, selection, implementation, execution' (March, 1991, p. 71).

Several factors drive heterogeneity in innovative outputs. Radical innovation represents a recombination of relatively distant, often external, knowledge that generates truly novel ideas; this type of innovation is associated with high uncertainty, but promises to generate substantial long-term returns for innovating firms (Dewar and Dutton, 1986). Radical innovation is strongly dependent on highly specialized, technical human capital and R&D investments (Dewar and Dutton, 1986; Subramaniam and Youndt, 2005), science-driven search practices emphasizing university ties, patents, and knowledge acquisition (Köhler et al., 2012; Zhou and Li, 2012) and a deeper, narrower external search (Laursen and Salter, 2006), systematic knowledge management practices (Cantner et al., 2011), and previous breakthroughs or history of engaging with novel technologies (Ahuja and Lampert, 2001; Dunlap-Hinkler et al., 2011). In sum, radical innovation is more tightly connected to technical skills and the discovery or invention stage of product development: that is, specialist scientific human capital should matter more than entrepreneurial human capital for this type of innovation.

Conversely, incremental innovation generates commercial success by exploiting firms' existing knowledge assets in new ways (Dewar and Dutton, 1986; Gatignon et al., 2002); technical human capital and R&D investments retain some importance (Laursen and Salter, 2006; Cantner et al., 2011; Leiponen and Helfat, 2011), but this form of innovation exhibits closer ties with insight into firms' competitive landscape and a generalist profile.[8] For example, firms engaging in search strategies with a market orientation, focusing on customers and competitors, are more likely to generate successful incremental innovation (Köhler et al., 2012), as are firms drawing broadly from external sources (Laursen and Salter, 2006; Leiponen and Helfat, 2011). Additionally, the ability to share knowledge internally and externally among employees, customers, suppliers, and partners favors marginal improvements (Subramaniam and Youndt, 2005). As a result, incremental innovation is linked less to the research than to the development stage, where insight into available resources and market needs may prove more valuable.

While execution skills do not exclude a technical component – evaluating knowledge assets may even require a certain technical competence, they emphasize the ability to create market opportunities and resource configurations less visible to workers without such skills (Foss and Klein, 2012); entrepreneurial human capital should thus lend itself more to incremental than to radical innovation. Former founders' stronger previous contact with customers, competitors, suppliers, and other complementors allows for broader insight into the competitive landscape, enhancing firms' market-oriented search. The generalist dimension of execution skills further allows entrepreneur hires to more effectively acquire information and resources across domains, aiding internal knowledge sharing. Former founders' value added thus lies to a larger extent in bringing to market more marginal improvements in firms' product and service offerings than in developing the technical areas that favor radical innovation, so we posit that:

[8] Incremental innovation is sometimes associated with imitation, underscoring the importance of market knowledge. Relative to radical innovation, incremental innovation may also require speed to market rather than intellectual property rights (Lee et al., 2000; Gans and Stern, 2017; Ching et al., 2019), so resource acquisition and mobilization advantages again favor incremental over radical innovation.

**Hypothesis** *3 The positive relationship between hires with founder experience and sales from innovation is stronger for incremental relative to radical innovation.*

In sum, our theoretical framework predicts that entrepreneur hires benefit firm innovation through a generalist ability to configure the requisite resources for bringing new ideas to market. We expect stronger effects for middle management hires, where execution skill deployment is facilitated by broader decision rights, and for incremental innovation, where insight into available markets and resources favor marginal improvements.

## 2.3 Data

### 2.3.1 Empirical Setting

We test our predictions empirically in Denmark, a context that features several key properties. First, the rich data available from the national statistics agency, Statistics Denmark, allows us to analyze a host of innovation outcomes while tracking individual career histories in detail. Second, Denmark has a thriving entrepreneurial ecosystem, ensuring an adequate supply of founders available for firms to hire; the Danish labor market is highly flexible, so career trajectories are dynamic, with substantial moves to and from entrepreneurship. Finally, the presence of (globally) innovative firms affords us with variation in our outcomes of interest.

### 2.3.2 Community Innovation Survey Data

To measure firm innovation, we rely on the Danish Community Innovation Survey (CIS). This survey is based on the Oslo Manual designed to collect self-reported data on R&D activities and innovation of European firms and is a major source of information for innovation research (for instance, Cassiman and Veugelers, 2006; Laursen and Salter, 2006; Leiponen and Helfat, 2010; Klingebiel and Rammer, 2014). Statistics Denmark took over the administration of the CIS in 2007, when the data collection approach also changed; we therefore construct our sample starting in 2007 to ensure consistency in our dependent variables. The data is collected yearly through an online survey at the central webpage for tax reporting by firms registered in Denmark and participation is mandatory for selected firms, so we avoid non-response or attrition issues. The CIS relies on stratified random sampling to ensure coverage across industries facing international competition and excludes state-owned enterprises; sampling intensity is higher for high-R&D industries, as well as larger firms, with around 4,500 firms participating in the survey annually. Our final panel dataset for the years 2007-2016 is unbalanced, although most firms complete the CIS multiple times. We link the CIS data to the general firm register – including all firms in Denmark – to obtain additional information on employment and investments; we also link our dataset to patent data to obtain technical output measures.

### 2.3.3 Linked Employer-Employee Data

Our main data source for identifying entrepreneurs is the Integrated Database for Labor Market Research (IDA) containing linked employer-employee information on the full Danish workforce from 1980 onward. The IDA database is recognized for its ability to reliably track both firms and workers over time and is often used in entrepreneurship and innovation research (e.g., Dahl and Sorenson, 2012; Kaiser et al., 2018; Rocha and van Praag, 2020). However, due to a change in the key that uniquely identifies firms, we track individual career histories from 1999 onward; the IDA data includes all firms in Denmark associated with at least one individual, excluding holding or shell companies. We match these firms with the general firm register to obtain the year of establishment, which we use to identify new firms. We also match the individual level observations with two other registers containing information on worker occupation (International Standard Classification of Occupations or ISCO codes) and education. We aggregate individual observations to the firm level by computing counts of individuals (e.g., new entrepreneur hires) before merging with the CIS data. Since we are interested in established firms' innovation, we restrict our sample to firms more than five years old and with more than 25 employees, counting only individuals who have their main occupation with the firm.

### 2.3.4 Dependent Variables

Given our theoretical focus on taking innovation to market, our main dependent variable in testing Hypotheses 1 and 2 is the share of Sales from innovation. This variable captures the share of revenue derived from new and improved products and services, and ranges from zero to a hundred percent in a given year. To test Hypothesis 3, we disaggregate our dependent variable into shares of Sales from innovation new to the firm, Sales from innovation new to the market and Sales from innovation new to the world, capturing progressively more radical new offerings. Often used as proxies for innovation activities in prior work (Cassiman and Veugelers, 2006; Laursen and Salter, 2006; Leiponen and Helfat, 2010), these measures are especially well-suited to our study as the fraction of revenue obtained from new offerings speaks directly to the function we posit former entrepreneurs perform inside established organizations: unlocking the economic significance of innovation (Grimpe and Kaiser, 2010). Our sales-based variables also allows us to capture innovation more broadly than more technical, traditional measures, as only a small fraction of firms exhibit regular patenting activities. Nonetheless, we use Any patents, Number of patents and Citation-weighted patents as dependent variables to assess whether entrepreneur hires generate new technical knowledge.

### 2.3.5 Independent Variables

Correctly identifying entrepreneurs is a key challenge for our study. Since the execution skills we theorize founders bring to the hiring firm come from running a start-up with growth potential, we define entrepreneurs as founders of an incorporated start-up with employees. We use Statistics Denmark's general firm registry to identify new firms, using their date of registration as a legal entity. We define a new firm as one registered in the current or previous year (age zero or one) and with at most 25 employees including the founder at founding, thus excluding spin-offs from existing companies. Identifying incorporated firms' founders is not straightforward. Following Sørensen (2007), we identify founders as individuals working at a new firm with at most three employees; if the new firm consists of more than three workers, we identify founders as employees in managerial roles; and absent managerial roles, we count the top three earners as founders. We exclude founders who do not hold their main occupation with the firm until year three of its existence, as well as solo ventures within this time frame. This approach, capturing engagement in a meaningful start-up's early life, allows us to measure founding experience in a way that reflects our theoretical interest in entrepreneurial human capital.

For our analysis, we consider year zero or one founding experience within the five years prior to the hiring event, focusing on observations where the focal firm provides the individual's main occupation. To assess labor inputs' relative impact on innovation, we split the workforce into three distinct groups: Hires with founder experience, Hires without founder experience, and Stayers. We also disaggregate founder hires into those occupying Top management, Middle management, and Non-management roles in the hiring firm: we use 1-digit ISCO codes to identify managers and 3-digit codes to identify top managers (ISCO = 11 or 121), then compute the shares of entrepreneur hires at each level. Moreover, we use ISCO codes to assess individuals' managerial experience and compute firms' share of Hires with managerial experience: contrasting this group with entrepreneur hires helps us examine the potential for managerial skills to confound our preferred execution skills channel. As current output depends on past inputs, we lag employment shares by one year.

### 2.3.6 Control Variables

We control for several variables that may determine firms' innovation outcomes and hiring decisions. We include logged Firm size as the total number of workers (based on main occupations), Firm age as years since establishment, and the logged book value of Physical capital. Following Kaiser et al. (2015), we consider individuals holding a higher education degree in STEM-related areas of technical, natural, health, veterinary, and agricultural sciences and occupying job functions requiring high levels of knowledge as R&D workers. We also control for the logged number of University graduates and include dummies for whether the firm has an R&D department, has Applied for patents or Acquired patents, as well as R&D intensity as R&D spending over revenue and the number of different formal R&D partner types as Collaboration breadth. We lag all IDA-derived measures in the estimation and include two lags of Sales growth and Investment intensity (net investment over revenue) as flexible time-varying proxies for the demand for execution skills. Finally, our main models include (2-digit NACE level) industry-year fixed effects, as well as firm fixed effects.

### 2.3.7 Descriptive Statistics

Our estimation sample, summarized in Table 1, comprises 20,271 observations for 3,846 firms. Firms' average share of sales from innovation is 11.4%, with almost half coming from offerings new to the firm (5.4%); those new to the market and world comprise 4.3% and 1.7% of sales, respectively. New entrepreneur hires are 0.5% of the workforce, reflecting the fact that many organizations do not hire entrepreneurs in a given year. Most hires occur in non-manager roles; 17 instead, non-founder hires and stayers represent 21% and 78% of the workforce, respectively. On average, firms are 27 years old and have 274 employees, of which 25 are R&D workers. Appendix Table A.1 displays the correlations between our main variables.

Table 1: **Descriptive statistics for the main variables,** $N = 20,271$

| | Mean | St. dev. | Min. | Max. |
|---|---|---|---|---|
| *Innovation outcomes* | | | | |
| Sales from innovation | 0.114 | 0.276 | 0 | 1 |
| Sales from innovation new to the firm | 0.054 | 0.181 | 0 | 1 |
| Sales from innovation new to the market | 0.043 | 0.162 | 0 | 1 |
| Sales from innovation new to the world | 0.017 | 0.101 | 0 | 1 |
| *Lagged employment shares* | | | | |
| Hires with founder experience | 0.00550 | 0.010 | 0 | 0.273 |
| ... in *top management* | 0.00007 | 0.001 | 0 | 0.053 |
| ... in *middle management* | 0.00023 | 0.002 | 0 | 0.041 |
| ... in *non-management* | 0.00520 | 0.010 | 0 | 0.273 |
| Hires without founder experience | 0.213 | 0.146 | 0 | 1 |
| Stayers | 0.781 | 0.149 | 0 | 1 |
| *Control variables* | | | | |
| Firm size | 274.903 | 1,009.146 | 26 | >33,500 |
| Firm age | 27.086 | 18.420 | 6 | >100 |
| Physical capital (thousand DKK) | 377.525 | 2,599.477 | 0 | >9,800,000 |
| R&D workers | 24.808 | 137.963 | 0 | >7,000 |
| University graduates | 46.960 | 181.409 | 0 | >8,800 |
| R&D department | 0.225 | 0.418 | 0 | 1 |
| R&D intensity | 0.023 | 0.102 | 0 | 1 |
| Collaboration breadth | 1.104 | 2.081 | 0 | 8 |
| Applied for patent(s) | 0.103 | 0.305 | 0 | 1 |
| Acquired patent(s) | 0.082 | 0.274 | 0 | 1 |
| Sales growth | 0.120 | 2.059 | -0.996 | >200 |
| Investment intensity | 0.041 | 0.095 | 0 | 1 |

## 1.4 Method

An ideal experiment to test our hypotheses would entail randomly assigning the quantity and quality of employees with and without entrepreneurial human capital to firms, whose innovative performance we could then track. In practice, the prohibitive cost of such an experiment renders our analysis vulnerable to several sources of endogeneity and bias, whose sign and magnitude are difficult to establish ex ante. We explain the identification and interpretation challenges we face and our approach to limiting their impact on our estimates below.

### 1.4.1 Identification Challenges

The first order concern for our identification strategy is the positive selection of more innovative firms into hiring entrepreneurs. If firms with a higher share of revenue from new products and services generally hire more entrepreneurs, firm innovativeness may confound our relationship of interest. However, Appendix Table A.2 shows that firms hiring former founders in a given year do not differ from those not hiring such workers in their innovation outcomes prior to the hiring event; they are also broadly similar along most observable dimensions. Firm fixed effects further alleviate this selection concern, but a dynamic effect may arise if firms hire founders when they anticipate additional market opportunities and demand execution skills. In our empirical analysis, we mitigate this potential issue by controlling for a broad set of firm attributes and including lagged sales growth and investment intensity as proxies for time-varying demand for former founders (Bloom et al., 2007; Michaely and Roberts, 2012).

A second order concern with interpreting our results is returning entrepreneurs' ability: if worse performers become employees, can we expect them to impact firms' innovation outcomes? Since moves to and from paid employment are common in entrepreneurial careers, founders becoming wage earners are not necessarily negatively selected (Burton et al., 2016; Dillon and Stanton, 2017; Failla et al., 2017), with both successful and unsuccessful exits determined by diverse (non-)business motives (Wennberg et al., 2010; DeTienne et al., 2015). Former founders thus form a general pool of human capital conducive to innovation, regardless of their success: negative selection would run counter to our assertion that they increase innovation, making our estimates lower bounds. Potential assortative matches between more innovative firms and better founders pose a subtler challenge, since our results should be interpreted as upper bounds for entrepreneur hires' effect on average firms' innovation.

### 1.4.2 Econometric Model

As Appendix A.1 details, we build on an innovation production function with multi-dimensional human capital inputs, a framework that allows us to calculate the relative impact of entrepreneur hires compared to other labor inputs under a set of weak assumptions (Kaiser et al., 2015, 2018). In practice, we estimate fixed effects ordinary least squares models, regressing innovation outcomes on lagged employment shares (alleviating reverse causality), firm characteristics, firm fixed effects (addressing time-invariant unobservables), lagged sales growth and investment intensity (addressing time-variant demand for former founders), and industry-year fixed effects (addressing common shocks).[9] Although they cannot be interpreted directly, positive employment share coefficients indicate higher innovation returns compared to stayers. More importantly, we test our hypotheses by comparing coefficients for Hires with founder experience and Hires without founder experience, which also helps us evaluate effect magnitude.[10] We perform similar calculations for comparing entrepreneur hires at different managerial levels and contrast coefficients across models when evaluating different innovation types. We cluster standard errors at the firm level throughout the analysis.

## 1.5 Results

### 1.5.1 Main Results

Table 2 presents our main estimation results. Model I tests Hypothesis 1, which predicts that a higher share of new entrepreneur hires is positively associated with firms' share of sales from innovation. In row (1), hires with founder experience are positively and significantly associated

[9] Pooled ordinary least squares or tobit models produce economically and statistically larger results (Appendix Tables A.3 and A.4). However, potential unobserved firm-level confounders justify using fixed effects. The lack of consecutive CIS observations for some firms prevents us from estimating dynamic panel models.
[10] We calculate effect sizes as $(\beta_{\text{Founder}} + \beta_{\text{Firm size}})/(\beta_{\text{Non-founder}} + \beta_{\text{Firm size}})$ (Appendix A.1). The estimated coefficients do not translate directly into elasticities due to the composite labor index used (Kaiser et al., 2018). The negative *Firm size* coefficient precludes us from calculating meaningful effect sizes relative to the baseline.

with sales from innovation relative to the baseline stayer category ($\beta = 0.502$, $p = 0.005$), but hires without founder experience in row (5) return a small and insignificant negative coefficient ($\beta = -0.008$, $p = 0.690$). Comparing these two estimates provides strong support for Hypothesis 1 ($p = 0.005$) and implies that an additional hire with founding experience contributes 24.7 times more (in absolute terms) to the hiring firm's sales from innovation relative to an additional hire without such experience. Moreover, detecting a short-term effect supports our argument that former entrepreneurs pursue an innovative idea, rather than generate inventions.

Hypothesis 2 proposes that new entrepreneur hires are more tightly linked to innovation when they occur in middle management positions, as opposed to top management or outside of managerial roles. To test this prediction, Model II substitutes employment shares corresponding to the different managerial levels for our main measure of entrepreneurial human capital. Within entrepreneur hires, those in middle management are the most strongly and positively correlated with innovation ($\beta = 2.625$, $p = 0.054$), followed by non-managers ($\beta = 0.236$, $p = 0.223$). These estimates are weakly statistically different ($p = 0.082$) and imply that entrepreneur hires in middle management contribute 11.6 times more to firm innovation relative to those in nonmanagerial roles. Entrepreneur hires in top management are, instead, negatively correlated with firm innovation, although this result is not statistically significant ($\beta = -2.081$, $p = 0.126$).[11] Comparing estimates for hires with founding experience across managerial layers returns a significant difference ($p = 0.016$) and implies that middle management entrepreneur hires contribute 1.2 times more (in absolute terms) to hiring firms' innovation than those in top management. A joint test of hires in middle management relative to those in other positions provides further support for

[11] The small fractions of entrepreneur hires in managerial positions (see Table 1) produce large standard errors for these categories, which may inflate p-values for the hypothesis tests in Table 2. Moreover, a concern with this set of estimates lies in the potential selection of better entrepreneurs into higher managerial levels; our finding that entrepreneur hires in top management do not affect the share of sales from innovation speaks against this explanation. However, the negative coefficient for top management founder hires could arise if they occur during periods of especially poor innovative performance (despite our controls for sales growth).

Hypothesis 2 ($p = 0.053$) and highlights the importance of matching entrepreneurial human capital with the relevant decision rights and access to resources.

We test Hypothesis 3 by estimating models separately for innovation that ranges from the most incremental (new to the firm) to the most radical (new to the world). In Model III, hires with founder experience are positively and significantly associated with sales from innovation new to the firm relative to stayers ($\beta = 0.256$, $p = 0.036$), whereas hires without founder experience return an insignificant coefficient ($\beta = 0.004$, $p = 0.755$). These estimates are significantly different ($p = 0.040$) and imply that an additional hire with founding experience contributes 55.1 times more (in absolute terms) to the hiring firm's sales from incremental innovation than an additional hire without such experience. The equivalent coefficients for offerings new to the market in Model IV are 0.163 ($p = 0.125$) and -0.017 ($p = 0.124$) for hires with and, respectively, without founding experience. This weakly significant difference ($p = 0.095$) entails a 10.6 times larger contribution (in absolute terms) to firms' offerings new to the market for an additional entrepreneur hire compared to a non-entrepreneur hire. In Model V, we find no significant effect of either hire type on innovation new to the world ($\beta = 0.083$, $p = 0.249$; $\beta = 0.005$, $p = 0.516$) or a difference between them ($p = 0.286$). As we analyze progressively more radical types of innovation, the effect of new founder hires becomes economically and statistically smaller, highlighting the important role entrepreneurial human capital plays for incremental improvements to firms' offerings, as Hypothesis 3 predicts.

Table 2: **The effect of entrepreneur hires on firms' sales from innovation**

| | | Model I: Sales from innovation | | | Model II: Sales from innovation | | | Model III: Sales from innov. new to firm | | | Model IV: Sales from innov. new to market | | | Model V: Sales from innov. new to world | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| | *Lagged employment shares* | | | | | | | | | | | | | | | |
| (1) | Hires with founder experience | 0.502 | 0.005 | 0.180 | | | | 0.256 | 0.036 | 0.122 | 0.163 | 0.125 | 0.106 | 0.083 | 0.249 | 0.072 |
| (2) | ... in *top management* | | | | -2.081 | 0.126 | 1.358 | | | | | | | | | |
| (3) | ... in *middle management* | | | | 2.625 | 0.054 | 1.362 | | | | | | | | | |
| (4) | ... in *non-management* | | | | 0.236 | 0.223 | 0.194 | | | | | | | | | |
| (5) | Hires without founder experience | -0.008 | 0.690 | 0.020 | -0.002 | 0.921 | 0.020 | 0.004 | 0.755 | 0.014 | -0.017 | 0.124 | 0.011 | 0.005 | 0.516 | 0.008 |
| | *Control variables* | | | | | | | | | | | | | | | |
| | Log firm size | -0.012 | 0.181 | 0.009 | -0.011 | 0.211 | 0.009 | -0.009 | 0.170 | 0.006 | 0.002 | 0.747 | 0.005 | -0.005 | 0.172 | 0.003 |
| | Log physical capital | -0.003 | 0.287 | 0.002 | -0.003 | 0.271 | 0.002 | -0.003 | 0.063 | 0.001 | -0.000 | 0.957 | 0.001 | 0.000 | 0.900 | 0.001 |
| | Firm age | 0.002 | 0.000 | 0.001 | 0.002 | 0.000 | 0.001 | 0.002 | 0.000 | 0.000 | 0.001 | 0.076 | 0.000 | -0.000 | 0.432 | 0.000 |
| | Log R&D workers | 0.011 | 0.085 | 0.006 | 0.010 | 0.087 | 0.006 | 0.010 | 0.026 | 0.004 | 0.000 | 0.956 | 0.004 | 0.000 | 0.805 | 0.002 |
| | Log university graduates | -0.008 | 0.263 | 0.007 | -0.008 | 0.288 | 0.007 | 0.001 | 0.824 | 0.005 | -0.009 | 0.061 | 0.005 | -0.001 | 0.787 | 0.002 |
| | R&D department | 0.120 | 0.000 | 0.014 | 0.120 | 0.000 | 0.014 | 0.064 | 0.000 | 0.010 | 0.046 | 0.000 | 0.009 | 0.010 | 0.011 | 0.004 |
| | R&D intensity | 0.067 | 0.286 | 0.063 | 0.066 | 0.288 | 0.062 | -0.012 | 0.773 | 0.043 | 0.025 | 0.490 | 0.036 | 0.054 | 0.281 | 0.050 |
| | Collaboration breadth | 0.018 | 0.000 | 0.002 | 0.018 | 0.000 | 0.002 | 0.009 | 0.000 | 0.001 | 0.007 | 0.000 | 0.001 | 0.002 | 0.015 | 0.001 |
| | Applied for patent(s) | 0.017 | 0.268 | 0.016 | 0.018 | 0.254 | 0.016 | -0.009 | 0.429 | 0.011 | 0.017 | 0.077 | 0.010 | 0.009 | 0.097 | 0.005 |
| | Acquired patent(s) | 0.029 | 0.012 | 0.012 | 0.029 | 0.013 | 0.012 | 0.008 | 0.310 | 0.008 | 0.017 | 0.020 | 0.007 | 0.004 | 0.486 | 0.005 |
| | Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| | Industry-year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| | Firm fixed effects | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| | Number of observations/firms | 20,271/3,846 | | | 20,271/3,846 | | | 20,271/3,846 | | | 20,271/3,846 | | | 20,271/3,846 | | |
| | Adjusted $R^2$ | 0.310 | | | 0.310 | | | 0.198 | | | 0.206 | | | 0.267 | | |
| | *F-tests* | | | | | | | | | | | | | | | |
| | Hypothesis 1: (1)=(5) | 7.82 | 0.005 | | | | | 4.21 | 0.040 | | 2.79 | 0.095 | | 1.14 | 0.286 | |
| | Hypothesis 2: (3)=(2) | | | | 5.86 | 0.016 | | | | | | | | | | |
| | Hypothesis 2: (3)=(4) | | | | 3.03 | 0.082 | | | | | | | | | | |
| | Hypothesis 2: (3)=(2) *and* (4) | | | | 2.93 | 0.053 | | | | | | | | | | |

Robust standard errors clustered by firm. Sample restricted to firms older than 5 years and with more than 25 employees, for years 2007-2016; stayers represent the baseline category. All models estimated by ordinary least squares with firm fixed effects.

Before turning to sensitivity analyses, we test an alternative counterfactual for our arguments relating execution skills to hierarchical position leading up to Hypothesis 2. Namely, we check whether entrepreneurs and non-entrepreneurs hired in middle management roles differ in their effects on firm innovation in Appendix Table A.5. Non-entrepreneur middle manager hires are not significantly associated with any of our innovation outcomes (neither are non-entrepreneurs in other roles), while entrepreneur hires in middle management are positively associated with sales from innovation ($p = 0.054$), especially for innovation new to the firm ($p = 0.038$). The differences between the two groups for these outcomes are significant ($p = 0.061$ and, respectively, $p = 0.026$), indicating that the central authority and decision rights associated with middle management is particularly well-suited for the deployment of entrepreneurial human capital in pursuit of (incremental) innovation.

### 1.5.2 Alternative Explanations and Robustness Checks

In this section we test competing explanations of entrepreneur hires' effect on firm innovation based on technical or managerial skills and investigate the robustness of our results to alternative dependent variable, independent variable, and sampling choices. Our core argument is that former founders improve innovation through execution skills, but a similar outcome may arise if they help established firms gain access to new technical knowledge. To test this channel, we use firms' possession of Any patents, Number of patents, and Citation-weighted patents as alternative dependent variables that better reflect technical skills and invention outcomes in Table 3, Models A-VI-VIII. We do not find any effects of new entrepreneur hires on either of these patent-based measures (all $p > 0.6$), suggesting that former founders' technical skills (or intellectual property rights) cannot explain our findings.[12]

We obtain similarly insignificant results with Any sales from innovation as a dependent variable (Appendix Table A.4, Model A-XII), implying that new entrepreneur hires improve firm innovation along the intensive, but not necessarily extensive margin. In other words, they are more valuable to firms already engaged in innovation activities and that possess potentially underused technical knowledge or ideas, shoring up our theoretical focus on innovative firms. Accordingly, our findings are stronger when we restrict the analysis to innovation-active firms during the sample period ($\beta = 0.584$, $p = 0.006$) or innovation-active observations only ($\beta = 1.095$, $p = 0.002$). These results may also suggest that entrepreneurs do not automatically bring in valuable innovations from their previous firm; in other words, the value they create is due to their human capital, rather than other types of inputs.

As entrepreneurs perform a variety of managerial functions in their start-ups, an alternative explanation for our findings may be that they learn to manage, but not necessarily execute new ideas. In other words, their advantage relative to hires without founding experience may stem not from the ability to develop new business opportunities based on existing knowledge in non-routine settings, but from deploying general skills in routine functions such as goal-setting, operational, monitoring, or personnel practices (Bloom and van Reenen, 2007). We evaluate this potential confounding channel by measuring individuals' previous managerial experience – whether they

[12] New entrepreneur hires may also occur through 'acquihires', which may bring in both entrepreneurial human capital and innovative projects, as well as intellectual property rights. This is a rather new and relatively rare phenomenon in Denmark; when acquisitions occur, they tend to involve older companies than those we consider start-ups in our analysis. We do address this possibility directly, using workplace identifiers and worker mobility to define acquihires in Appendix A.2. Only 0.6% of hiring events in our analysis sample are acquihires, of which 2.9% are former +founders; more generally, only 0.4% of IDA hiring events in the same years come from acquihires, of which 3.2% are former founders. Disaggregating entrepreneur hires by their origin or dropping observations with acquihires, Appendix Table A.6 shows that our main estimates retain significance ($p \leq 0.002$) and slightly increase in magnitude. Acquihires are thus unlikely to explain our results.

occupied a management position in the five years prior to hiring – and pitting it against entrepreneurial experience (Busenitz and Barney, 1997; Koudstaal et al., 2016)

Empirically, we regress our main outcome variable, Sales from innovation, on three distinct employment shares: Hires with founding experience, Hires with managerial experience, and Hires without founding or managerial experience. Model IX in Table 3 suggests that new entrepreneur hires remain positively and significantly correlated with firm innovation ($\beta = 0.501$, $p = 0.006$), whereas new managerial hires exhibit a weaker, insignificant association ($\beta = 0.185$, $p = 0.211$). Although these coefficients are not statistically different from each other ($p = 0.133$, possibly due to the low employment shares in each group), they are economically distinct, as new entrepreneur hires contribute 3.3 times more than new managerial hires to innovation in this model. Moreover, the effect of entrepreneur hires on innovation is virtually unchanged from that in Table 2 when we control for managerial hires, suggesting they might capture different inputs to innovation. We thus conclude that while entrepreneurial human capital may encompass routine managerial skills, an important role remains for execution skills connecting existing knowledge with market insight to generate new business opportunities.

Along a similar line of inquiry, we broaden our investigation to compare founder experience to general management, sales, and R&D experience. To avoid overlapping categories, we focus on individuals' last role prior to the focal hiring event and regress our innovation outcomes on the share of hires with each type of experience (including a residual category) in Appendix Table A.7. We first replicate our previous results on founder ($\beta = 0.655$, $p = 0.021$) relative to manager ($\beta = 0.163$, $p = 0.330$) experience: although the difference in their economic magnitude is larger, these estimates are not statistically different ($p = 0.134$). We also uncover significant differences between founder hires and hires with sales ($p = 0.015$), R&D ($p = 0.052$), or 'other' ($p = 0.021$) experience with regards to sales from innovation; the latter types of experience are, in fact, not significantly linked to innovation. We observe a similar pattern for innovation new to the firm and market, but we do not find significant effects or differences for innovation new to the world. Overall, these results strengthen our confidence in execution skills – rather than managerial, sales, or technical skills – as the likely explanation for the positive effects of entrepreneur hires on firm innovation.

We subject our independent variables to additional checks in Appendix Table A.4. First, whereas our main analysis identifies founders only in years zero and one of their start-up, we consider an alternative definition where we allow founders to be recorded as such for up to three additional years, provided they remain with the firm. This expands the number of individuals for whom we record entrepreneurial experience within the past five years, but implies that start-up experience (i.e. in the venture's first two years) is somewhat more distant from the hiring event. The results are similar to those in Table 2, although their magnitude decreases slightly: in Model A-VI, the coefficient is now 0.396 ($p = 0.019$) as opposed to 0.502 ($p = 0.005$). The depreciation of entrepreneurial human capital provides one potential explanation for this pattern, with more recent experience having larger effects on innovation. To probe this explanation further, we reestimate our models computing the shares of hires with and without founding experience based on the year prior to the hiring event: if entrepreneurial human capital depreciates quickly, more recent founding experience should produce larger effects on innovation. This is indeed what we find, with a Model A-VIII coefficient of 0.637 ($p = 0.025$), implying that hiring firms benefit more from hiring individuals with more recent entrepreneurial experience.

Table 3: **Alternatives to execution skills: technical and managerial skills**

| | | Model VI: Any patents | | | Model VII: Number of patents | | | Model VIII: Citation-weighted patents | | | Model IX: Sales from innovation | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| | *Lagged employment shares* | | | | | | | | | | | | |
| (1) | Hires with founder experience | 0.008 | 0.939 | 0.107 | 0.295 | 0.626 | 0.604 | -0.116 | 0.933 | 1.381 | 0.501 | 0.006 | 0.180 |
| (2) | Hires without founder experience | -0.032 | 0.032 | 0.015 | 0.014 | 0.942 | 0.196 | -0.102 | 0.866 | 0.604 | | | |
| (3) | Hires with managerial experience | | | | | | | | | | 0.160 | 0.269 | 0.144 |
| (4) | Hires without either experience | | | | | | | | | | -0.017 | 0.414 | 0.021 |
| | Control variables | Yes | | | Yes | | | Yes | | | Yes | | |
| | Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | |
| | Industry-year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| | Firm fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| | Number of observations/firms | 10,753/2,822 | | | 10,753/2,822 | | | 10,753/2,822 | | | 20,271/3,846 | | |
| | Adjusted $R^2$ | 0.555 | | | 0.818 | | | 0.593 | | | 0.310 | | |
| | *F-tests* | | | | | | | | | | | | |
| | Technical skills: (1)=(2) | 0.14 | 0.705 | | 0.21 | 0.649 | | 0.00 | 0.993 | | | | |
| | Managerial skills: (1)=(3) | | | | | | | | | | 2.26 | 0.133 | |

Robust standard errors clustered by firm. Sample restricted to firms older than 5 years and with more than 25 employees, for years 2007-2012, when patent data is available (and years 2007-2016 in Model IX); stayers represent the baseline category. All models estimated by ordinary least squares with firm fixed effects. In Models V-VII, the means of the dependent variables are 5.2% (*Any patents*), 0.402 (*Number of patents*), and 0.464 (*Citation-weighted patents*); in Model VIII, the mean share of hires with managerial experience is 0.9%, with a standard deviation of 0.015.

Second, one year of start-up experience (i.e. during a new venture's years zero or one) is enough to identify a founder in our main analysis, reflecting our interest in start-ups' early life, when execution skills are developed. However, this raises the question of whether brief spells in entrepreneurship – potentially reflecting failed projects – lead to enhanced execution skills or whether longer, sustained founding experience is needed. To evaluate this, we re-calculate our measures of entrepreneurial human capital requiring individuals to have been with the venture at least two consecutive years (i.e. years zero and one, or one and two). If short-term engagement does not build execution skills, the estimated Hires with founding experience coefficient should increase; otherwise, it should remain essentially unchanged. Using these independent variables produces broadly similar effect sizes to those in Table 2 (Model A-VII, $\beta = 0.387$, $p = 0.095$), implying that entrepreneurial human capital is developed even through brief engagement during a new venture's early life; this may suggest that both failure and success are linked with learning and entrepreneurial human capital development and that short-term experimentation provides valuable skill acquisition opportunities (Manso, 2016; Mérida and Rocha, 2021).

Third, we subject the possibility that more entrepreneurial firms hire more former founders to an alternative test, regressing our measures of innovation on leads of the employment shares: a positive and significant effect would imply that reverse causality can explain our results. We find that future entrepreneur hires do not affect innovation outcomes: when analyzing Sales from innovation in Model A-IX, this variable returns a coefficient of 0.070 ($p = 0.719$). The evidence therefore speaks against reverse causality driving our findings.

Fourth, our theoretical framework guides our analysis of human capital flows, but we can also assess the effects of its accumulation as a stock. We compute the share of Workers with founder experience (mean of 1.2%) and use it as an independent variable. The results point towards a significant positive effect of entrepreneurial human capital stocks on sales from innovation ($\beta = 0.370$, $p = 0.052$) in Model A-X, albeit statistically weaker than the one for flows.

As before, its positive association with innovation new to the firm is significant ($\beta = 0.250$, $p = 0.067$), but the one with innovation new to the world is not ($\beta = 0.135$, $p = 0.159$). So, while entrepreneurial human capital accumulation matters, the inflow of execution skills and market insight may be more important for firm innovation, in line with our depreciation argument.

Fifth, our analysis considers all employees who report a firm as the provider of their main occupation, although some roles require no specific knowledge or qualifications and are unlikely to affect innovation. When we exclude such positions from our firm size and employment shares calculations, the results are similar to those in Model I ($\beta = 0.495$, $p = 0.025$), as would be the case if most entrepreneurs are hired in positions above this level and the new variables were simply re-scaled versions of our main independent variables.

Finally, we assess the robustness of our results to sampling decisions. Our focus on established firms as recipients of entrepreneurial human capital guided our decision to analyze firms more than five years old and with more than 25 employees, but these cutoffs are arguably subjective. As a check, we use alternative age cutoffs from more than three to more than 100 years old, estimating our main specification in each new sample. We find consistent effects in sign, size, and significance for all cutoffs up to 30 years, where they begin to weaken, partly due to smaller sample size; the effect is much lower for firms over 40 years old and becomes weakly negative, but insignificant, for the oldest firms. We also use size cutoffs ranging from more than 10 to more than 500 employees. We find consistent results for cutoffs from 15 to 200 employees (but not smaller), where the effect weakens both economically and statistically. That larger, older firms benefit less from entrepreneur hires is an important boundary condition, with these firms' deeply entrenched routines and business models making it more difficult to integrate and act upon entrepreneurial human capital; that smaller ones are also less affected rules out that start-up hiring drives our effects.

## 1.6 Discussion

**Theoretical implications** Finding that entrepreneur hires improve firms' ability to benefit from new products and services, we show how innovation and entrepreneurship interface to generate growth opportunities, linking two distinct strands of literature. Our results highlight the importance of entrepreneurial human capital – former founders' execution skills for bringing ideas to market – as a scarce and valuable resource for firms' innovative performance (Alvarez and Busenitz, 2001; Foss and Klein, 2012). We provide evidence for one possible way organizations can acquire entrepreneurial capabilities (Teece, 2016; Distel et al., 2019; Faleye et al., 2020), a function whose determinants have received limited attention despite recognition that 'entrepreneurial action is required to transform knowledge investments from possessing the potential to create value into a form that enables its appropriation' (Agarwal et al., 2010, p. 271). The capacity to configure resources and bring new ideas to market by hiring entrepreneurs thus allows firms to appropriate a larger share of the value they create (Teece, 1986).

Our work contributes directly to a growing literature on hiring-for-innovation. Building on studies showing that hiring inventors has a strong impact on the earlier, patenting stage of the innovation process (Almeida and Kogut, 1999; Rosenkopf and Almeida, 2003; Song et al., 2003; Tzabbar, 2009; Palomeras and Melero, 2010; Singh and Agrawal, 2011; Kaiser et al., 2018), we emphasize a novel human capital input, entrepreneurial execution skills, into a later stage of the innovation process, namely bringing ideas to market. Our study therefore raises an important question regarding the interaction of these different inputs for increasing the value firms generate and appropriate. When is an entrepreneur hire more valuable than a inventor hire, are they complements or substitutes, and does this vary with the innovation type considered? Answering these questions could be invaluable to firms as they direct their external hiring processes.

In theorizing and showing a stronger effect of entrepreneur hires in middle management on innovation, this paper also highlights the importance of organizational design for human capital deployment (Teece, 1996; Garicano, 2000; Foss et al., 2015). By virtue of greater decision rights and hierarchical position, middle managers perform crucial information processing and resource allocation functions in organizations (Wooldridge et al., 2008; Mollick, 2012). Former founders' advantage in linking market insight with firms' technical assets translate into improved performance as selection agents when they occupy middle management roles; moreover, entrepreneur hires in such roles can better acquire and mobilize resources across dispersed gatekeepers than hires in other hierarchical positions. Matching entrepreneurial human capital and decision rights (Foss and Klein, 2012) is thus vital for execution skills to reach their innovation potential.

Our results suggest that entrepreneur hires in top management are not significantly related to firm innovation, in seeming contrast to what Faleye et al. (2020) find for board hires. However, top managers' responsibilities lie mainly in outlining strategy and providing a vision for the firm (including R&D spending increases across the entire firm, for instance), actions that may take longer to materialize as sales from innovation; the outcomes Faleye et al. (2020) study speak to external audiences' perception of firm value and are far more proximate to the hiring event. Understanding the dynamic effects of entrepreneurial human capital on firm innovation and performance presents an important dimension along which our work could be extended.

The core premise of our theoretical framework is that former founders possess a combination of innate and, especially, acquired entrepreneurial human capital (albeit subject to depreciation). The execution skills advantage former entrepreneurs enjoy over non-entrepreneur enhances their effectiveness in seeking, acquiring, and mobilizing heterogeneous social, human, or financial capital resources to pursue novel market opportunities building on under-utilized knowledge. Consequently, we propose and document that entrepreneur hires are more tightly linked to incremental innovation, which finds new uses for existing assets, than to radical innovation, more dependent on technical human capital and investments. That is, execution skills are relatively more helpful in detecting and implementing more marginal, possibly imitative, improvements to firms' product and service offerings. Yet, substantial business R&D is directed towards imitative products and incremental innovation accounts for a fair share of firm revenues (Leiponen and Helfat, 2011), so improvements along this dimension could still be efficiency-enhancing.

We conceptualize entrepreneurial human capital as a unique bundle of execution skills. This notion closely relates to entrepreneurial judgment under uncertainty, or 'decisive action about the deployment of economic resources when outcomes cannot be predicted according to known probabilities' (Foss and Klein, 2012, p. 38). For these authors, entrepreneurial judgment is not contractible or tradable due to the fundamental uncertainty around heterogeneous resource configuration. Our results suggest that entrepreneurial behavior can be traded, albeit imperfectly: previous founding experience is a valuable, though possibly noisy indication that individuals possess entrepreneurial judgment that could be fruitfully deployed inside established firms. This study also links definitions of entrepreneurship as outcome (e.g. firm formation) and function, namely that entrepreneurs create and exploit strategic opportunities. Defining entrepreneurship remains a fundamental, challenging task, but the substantial overlap between alternative interpretations offers a positive upshot for scholars in this area.

In showing how entrepreneurs are valuable for established organizations, we contribute to research on entrepreneurial careers (Burton et al., 2016; Failla et al., 2017; Manso, 2016). While a substantial share of (un)successful founders return to paid employment after entrepreneurial spells, firms may struggle to recognize their distinctive skill set, so former founders experience an initial earnings penalty (Mahieu et al., 2021); however, as execution skills are revealed, former entrepreneurs' wages rebound, displaying a long-run premium (Manso, 2016; Mérida and Rocha, 2021). Our paper helps explain former founders' wage dynamics, but also suggests that firms may capture short run value by capitalizing on entrepreneurs' possibly underrated skills. Future studies may inquire how the value former entrepreneurs generate is distributed between employee and firm. Moreover, studies of entrepreneurs' contribution to growth are possibly understated if limited to the value created by their start-ups, but not the firms they subsequently move to, an insight related to the finding that failed start-ups' patents spur substantial follow-on knowledge and value creation (Hoetker and Agarwal, 2007; Serrano and Ziedonis, 2018).

If hiring former entrepreneurs is associated with higher innovation sales, then why do some firms hire only a small share of such individuals? If in equilibrium firms balance the marginal costs and benefits of hiring entrepreneurs, our results imply some firms operate sub-optimally. A demand-side explanation for this potential inefficiency stems from the failure stigma facing unsuccessful entrepreneurs (Landier, 2006; Zunino et al., 2021), such that the expected benefits of founder hires are underestimated. This stigma not only hinders firm entry, but may limit entrepreneurship in established companies and impose larger costs on society as a whole than previously thought. Firms may also worry about integrating former founders into established structures. Entrepreneurs exhibit preferences for autonomy in contrast with existing bureaucracies (Corbett and Hmieleski, 2007; Sørensen, 2007; Butler, 2017), so a rigid environment would limit the ability to extract execution skills' full value. While one could bypass this problem by hiring former founders in middle management, affording them increased decision rights and autonomy, firms may be constrained in the availability of such positions. On the supply side, entrepreneurial human capital may indeed be scarce. A small fraction of the population enjoys recent founding experience and some may become serial entrepreneurs. A systematic inquiry into the drivers of entrepreneur hires could help unpack these explanations, providing valuable insight into where and how post-entrepreneurship careers unfold, as well as the availability of entrepreneurial human capital as a strategic input.

Our emphasis on entrepreneurial action inside established firms appears at odds with studies of employee entrepreneurship, where the 'abundance of under-exploited knowledge' is used outside the organization that generated it when employees deploy their human capital through spin-offs (Agarwal et al., 2004; Campbell et al., 2012b; Ganco, 2013; Gambardella et al., 2015). Yet, our argument is simply that firms can exploit the scientific and technical knowledge they produce by hiring the appropriate human capital. Former entrepreneurs' execution skills allow firms to appropriate a larger share of the value they create, thereby improving firms' incentives to generate knowledge in the first place and leaving them less liable to competition from ventures spawned otherwise. Disentangling entrepreneur hires' contribution to preventing spin-offs by exploiting technical knowledge in-house from their contribution to encouraging spin-offs by acting as role models for peers may represent a fruitful area for future research.

Finally, we speak to work on corporate (Covin and Miles, 1999; Kuratko et al., 2001; Burgers and Covin, 2016) and strategic (Hitt et al., 2001; Kuratko and Audretsch, 2009; Teece, 2016) entrepreneurship. We link a specific input to an innovation output through execution skills, but cannot test precisely how those skills are used (Teece, 2016). Future research could inquire how entrepreneurs differ from other employees in their ability to act as selection agents (Burgelman, 1991; Mollick, 2012), orchestrate resources inside the firm and assemble new venture teams (Burgelman, 1983a; Sirmon et al., 2011), or instill entrepreneurial spirit (Kuratko et al., 2001). Moreover, do organizations organically become more entrepreneurial by (inadvertently) hiring former founders or must they pursue a deliberate strategy to create innovation capabilities? Does hiring entrepreneurs signal an appealing environment to other former founders, helping develop an enterprising culture? Closely linking entrepreneurial inputs, processes, and outputs holds much promise for both researchers and practitioners.

**Managerial implications** A natural implication of our study is that companies hiring entrepreneurs may enjoy larger sales from new products and services. Our findings lend credence to the following quote from Dell's Entrepreneur-in-Residence, Ingrid Vanderveldt: "If a large corporation is going to stay relevant, they have to be innovative. Those corporations that reach out to embrace entrepreneurs can be the innovators. They are leading the way" (Smith, 2018). However, it is not enough to hire former founders; firms must also assign them to positions where execution skills can be better exploited. Middle management roles are particularly important, since they provide a compromise between market knowledge and access to firms' technical assets, as well as the decision rights necessary for acquiring and mobilizing resources (Foss and Klein, 2012). Although such positions may be scarce, moves towards flatter companies may aid the creation of middle manager positions; in turn, this organizational design choice can favor execution skill deployment (Foss et al., 2011, 2013).

Firms should also consider the type of innovation entrepreneur hires bring about: execution skills primarily build on firms' existing knowledge base and favor incremental relative to radical innovation, though they retain a positive effect on the latter. One may be concerned that such improvements are marginal or imitative, but this need not deter firms from hiring entrepreneurs. Companies allocate substantial resources to R&D activities directed at incremental innovation and extract significant value from it. Incremental product improvements may pave the way for strategic renewal, produce revenues to invest in developing radical inventions, and generate long-run competitive advantage (Covin and Miles, 1999). That said, entrepreneurial human capital is subject to depreciation, so regular inflows of founder hires may be needed for sustained innovation. To enhance their ability to recruit such human capital, firms should consider setting up human resource practices with a view towards avoiding the biases and blind spots that often preclude entrepreneurs from returning to the most relevant jobs (Butler, 2017).

**Limitations** Our study provides an initial foray into the effect of entrepreneurial human capital on firm innovation and is not without limitations. As noted, our observational data renders our analysis liable to endogeneity concerns. While we have done our best to tackle such concerns, our results could still be driven by unobserved confounders, such as changes in firms' innovation strategy. We nonetheless view our efforts as a first step in a systematic analysis of entrepreneurial human capital and firm performance. We are also limited in our ability to address specific mechanisms linking entrepreneur hires and innovation sales. Although we rule out alternative channels based on technical or managerial skills, we cannot pin down exactly how execution skills affect resource allocation. Moreover, former entrepreneurs may affect firms' inventive capabilities in more subtle ways than we pick up. By disaggregating turnover from innovation into its radical and incremental components we obtain results consistent with the idea that entrepreneur hires add relatively more value in identifying market gaps suitable for existing products with smaller improvements, although they still positively influence the more technical radical innovation. Future research using detailed patent data could more directly assess entrepreneurs' contribution to inventive activities, perhaps comparing the relative effects of execution, technical, and managerial skills, as well as their complementarity. Finally, subsequent work could explore worker and firm heterogeneity in founder/joiner experience, successful/unsuccessful venturing, organizational bureaucracy, or industry volatility.

**Conclusion** We propose that former entrepreneurs possess execution skills, a generalist ability to create opportunities by acquiring and mobilizing resources around new ideas, beneficial for employers' innovation. This effect is stronger when entrepreneur hires are coupled with middle management decision rights, while execution skills' generalist profile and accompanying market insight favor incremental over radical innovation. Our work opens a set of research avenues at the interface of innovation, entrepreneurship, and strategy.

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# Appendix A Supplementary Material

### A.1 Innovation Production Function

Our sales from innovation production function assumes a Cobb-Douglas specification regularly used in the innovation literature, including studies of hiring multi-dimensional human capital (Hausman et al., 1984; Blundell et al., 1995; Kim and Marschke, 2005; Kaiser et al., 2015, 2018). Our dependent variable is a firm's share of sales from innovation in a given year, $I$. This variable takes values in the $[0,1]$ interval and is a function of (entrepreneurial) labor and capital inputs. In turn, labor is a differentiated input: a firm's labor force, $L$, is split into newly hired entrepreneurs, $L_E$, newly hired non-entrepreneurs, $L_N$, and stayers, $L_S$, with $L = L_S+L_N+L_E$. To accommodate the fact that many firms will not hire former founders in any given year (an important feature of our data), we construct a composite measure of labor, $QL$, that combines the different human capital inputs in a linear, additive way (Griliches, 1967; Hellerstein et al., 1999; Galindo-Rueda and Haskel, 2005). Expressed as a function of this quality-adjusted labor input and suppressing firm and time indices, the Cobb-Douglas production function is:

$$I = AK^{\delta}QL^{\rho}, \tag{A.1}$$

where $K$ denotes capital input and $A$ includes additional control variables (other than capital or labor) such as industry, geographical, or time effects that we include in our empirical model. Each type of human capital $x$ adds to the $QL$ composite with a separate coefficient $\theta_x$ which measures its impact or marginal productivity relative to stayers (for whom the coefficient $\theta_S$ is normalized to 1), or the exchange rate at which one can be converted into the other (Griliches, 1967).[13] Our specification for quality-adjusted labor is then:

$$QL = L_S + \theta_N L_N + \theta_E L_E. \tag{A.2}$$

Expressing the count of stayers as a function of total labor force (i.e. firm size), newly hired non-entrepreneurs and newly hired entrepreneurs, and then factoring out the total labor force, the expression of quality-adjusted labor becomes:

$$QL = L(1 + ((\theta_N - 1)s_N + (\theta_E - 1)s_E), \tag{A.3}$$

where $s_N = L_N/L$ and $s_E = L_E/L$ are the shares of newly hired non-entrepreneurs and newly hired entrepreneurs in the total labor force, respectively. Since employment shares add up to one, excluding stayers from the estimation prevents the model from becoming perfectly collinear. Plugging in the expression for quality-adjusted labor, taking logs in equation A.1, and exploiting the fact that $\ln(1 + z) \approx z$ for small $z$ (which our employment shares satisfy), we obtain the following linear approximation for (the log of) innovation output:

[13] Note that this approach assumes the different types of labor are perfect substitutes, though this assumption can be relaxed with similar results (Hellerstein et al., 1999). This assumption also conveniently implies that the relative marginal productivity of labor type $x$ (to the excluded category) is constant, such that it does not depend on the employment levels in each category (Galindo-Rueda and Haskel, 2005).

$$\ln I = \ln A + \delta \ln K + \rho \ln L + \beta_N s_N + \beta_E s_E, \tag{A.4}$$

where $\beta_N = \rho(\theta_N - 1)$ and $\beta_E = \rho(\theta_E - 1)$.[14] Using the resulting $\hat{\beta}_N$, $\hat{\beta}_E$, and $\hat{\rho}$ estimates we can then back out the relative impacts $\hat{\theta}_x$ of labor input $x$ and test our theoretical hypotheses. Note that the many zero values introduced by our differentiated human capital inputs (especially new entrepreneur hires) preclude a standard log-linear specification, such that $\beta_N$ and $\beta_E$ do not translate directly into elasticities; however, a positive $\beta_x$ coefficient suggests that hiring an additional unit of labor type $x$ provides higher returns in terms of sales from innovation than would an additional stayer (the excluded category). More importantly, we can compare $\beta_N$ and $\beta_E$ in order to examine the innovation effects of hiring an entrepreneur relative to a non-entrepreneur as a direct test of our hypotheses. To understand the magnitude of our results, the relative effect of hires with founding experience relative to hires without founding experience can then be calculated as $\theta_E/\theta_N = (\rho + \beta_E)/(\rho + \beta_N)$.

Overall, this approach based on an innovation production function with differentiated labor inputs and a composite labor index provides a useful way of measuring the relative contributions of different employment shares to firm innovation. The empirical model we adopt easily extends to alternative dependent variables and additional employment shares, especially when comparing different types of innovation or entrepreneurial hires across managerial positions.

### A.2 Additional Analyses

Appendix Table A.1 displays pairwise correlations between our main variables, whose summary statistics we report in Table 1. To understand *which* firms are more likely to hire entrepreneurs to begin with, we provide a set of additional descriptive statistics for our CIS firms in Appendix Table A.2. Since most firms in our sample hire former founders at some point in the period we study, we focus on a snapshot comparing hiring and non-hiring firms in a given year in both a static and a dynamic perspective: we compare their attributes in the focal year, as well as averaged across the 3 prior years. We take 2013 as our focal year to ensure the dynamic perspective covers the midpoint of our sample period, although we have checked results are similar for other years. This exercise produces two key insights. First, CIS firms hiring entrepreneurs are broadly similar to those not hiring entrepreneurs in their age, R&D workforce, university graduates, general hiring rates, exports, investment intensity, geographical location, and industry representation. However, we observe differences in firm size: larger firms, which also have more capital, are more likely to hire at least one entrepreneur (a possibly mechanical effect); firms with a larger previous (Panel A), but not current (Panel B) sales growth are also more likely to hire entrepreneurs, which reinforces the need to control for multiple lags of sales growth in our analysis. Second, firms hiring former entrepreneurs are virtually identical to non-hiring firms in their past innovation success, with similar sales from innovation (regardless of type), as well as knowledge or collaboration breadth. The evidence in Appendix Table A.2 is thus important in alleviating selection concerns that innovative firms are more likely to hire former founders and reinforces our conclusion that entrepreneurial human capital is valuable for firm innovation.

[14] Based on the same approximation – $z \approx \ln(1 + z)$ for small $z$ – we directly regress the share of sales from innovation (which Table 1 shows is relatively low, on average) on employment shares, as well as control variables, firm fixed effects, and industry-year fixed effects.

Appendix Table A.3 provides the counterpart to our main estimates in Table 2 using ordinary least squares models without firm fixed effects. The results are similar across the two types of models, suggesting that time-invariant firm characteristics may not strongly affect the relationship between entrepreneurial hires and firm innovation; without firm fixed effects, the effect of entrepreneurial hires on sales from innovation becomes slightly more significant (Model A-II) and the coefficient on new entrepreneurial hires becomes a significant predictor of sales from innovation new to the market (Model A-IV). Although this exercise does not account for time-invariant firm-level confounders, it does allow for coefficient comparisons across models, where we find that founder hires have a significant association with innovation new to the firm or market, but not the world, i.e., with more incremental types of innovation.

Appendix Table A.4 then summarizes some of the robustness checks we discuss in the paper with regards to how we compute our independent variable: extending or restricting the time period we consider relevant for founding experience, focusing on direct moves from entrepreneurship to paid employment, and using stocks of former entrepreneurs as opposed to shares of new entrepreneurial hires (Models A-VI-X). We also show tobit estimates for our analysis of sales from innovation (Model A-XI), dealing with censoring in our dependent variable (although not with confounding time-invariant firm characteristics). All these alternative models support our main findings. We use *Any sales from innovation* as an alternative dependent variable (Model A-XII), pointing towards intensive margin effects as the main driver for our results.

In Appendix Table A.5 we assess an alternative counterfactual for entrepreneur hires in middle management: rather than comparing hierarchical layers within founder hires (e.g. top versus middle), we compare entrepreneur and non-entrepreneur hires within the same layer (i.e. in middle management). Empirically, we disaggregate both types of hires by the hierarchical position they are hired in and recompute employment shares; we then regress our innovation outcomes on these lagged employment shares in ordinary least squares models with firm fixed effects. We then report the results of statistical tests comparing entrepreneur and non-entrepreneur middle management hires. The results suggest that middle management entrepreneur hires are positively linked to sales from innovation and innovation new to the firm, whereas non-entrepreneur hires in similar positions are not, a statistically significant difference.

We directly address the role of entrepreneurs coming from acquihires in Appendix Table A.6. To identify acquisitions, we rely on Statistics Denmark's IDAS database, where workplaces are uniquely identified over time (firms can have several workplaces). Statistics Denmark applies an algorithm based on the individuals employed at a workplace to determine if that workplace is (dis)continued relative to the prior year. A workplace may continue existing, be discontinued entirely (by the firm), or – if at least 30% of employees (and at least two of them) move to the same *new* workplace – be absorbed by another workplace. If the new workplace's firm identifier is the same, this change represents an internal reorganization; if the firm identifier changes, the workplace was likely taken over via a merger or acquisition. We then match the IDAS workplace to our IDAN employee database to link workplaces to individuals and firms, allowing us to establish how entrepreneur hires join the focal firm. We focus on *focal* founders of acquired firms in Models A-XVII and A-XIX (disaggregating new hire variables and, respectively, dropping firm observations) and on *all* founders in acquired firms in models A-XVIII and A-XX (disaggregating new hire variables and, respectively, dropping firm observations). Albeit beyond the scope of our study, columns (1) and (2) show that both focal founders and former founders in acquired firms joining established firms through acquihires have a negative effect on innovation, consistent with studies showing higher dissatisfaction and exit rates for acquihired employees. Entrepreneur hires outside of acquisition events remain positively and significantly associated with innovation outcomes, even increasing slightly in magnitude.

Appendix Table A.7 then contrasts founder experience with experience acquired in (general) management, corporate sales, R&D, and 'other' roles. These models rely on employment shares computed by disaggregating individuals' position in the year prior to the focal hiring event, i.e. 'direct' hires, using sales from innovation and its components by innovation type as outcomes. We then report the results of statistical tests comparing hires with different types of experience. The analysis highlights founder hires' positive effect on sales from innovation (overall, as well as new to the firm and market), an effect larger in magnitude (but not statistically different) from that of hires with manager experience. However, founder hires' effect is greater and significantly different from that of hires with sales, R&D, or other types of experience.

Table A.1: **Correlation table**

| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) | (19) | (20) | (21) | (22) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | Sales from innovation | 1.00 | | | | | | | | | | | | | | | | | | | | | |
| (2) | ... new to firm | 0.70 | 1.00 | | | | | | | | | | | | | | | | | | | | |
| (3) | ... new to market | 0.66 | 0.07 | 1.00 | | | | | | | | | | | | | | | | | | | |
| (4) | ... new to world | 0.42 | 0.01 | 0.08 | 1.00 | | | | | | | | | | | | | | | | | | |
| (5) | Hires w/ founder experience | -0.03 | -0.01 | -0.03 | -0.02 | 1.00 | | | | | | | | | | | | | | | | | |
| (6) | ... in *top management* | -0.01 | -0.01 | -0.01 | -0.01 | 0.15 | 1.00 | | | | | | | | | | | | | | | | |
| (7) | ... in *middle management* | 0.03 | 0.02 | 0.01 | 0.01 | 0.21 | 0.01 | 1.00 | | | | | | | | | | | | | | | |
| (8) | ... in *non-management* | -0.03 | -0.01 | -0.03 | -0.02 | 0.98 | 0.03 | 0.03 | 1.00 | | | | | | | | | | | | | | |
| (9) | Hires w/o founder experience | -0.09 | -0.06 | -0.06 | -0.04 | 0.26 | 0.01 | 0.04 | 0.25 | 1.00 | | | | | | | | | | | | | |
| (10) | Stayers | 0.09 | 0.06 | 0.07 | 0.04 | -0.32 | -0.02 | -0.05 | -0.32 | -1.00 | 1.00 | | | | | | | | | | | | |
| (11) | Firm size | 0.04 | 0.04 | 0.01 | 0.01 | -0.03 | -0.01 | -0.01 | -0.03 | 0.04 | -0.04 | 1.00 | | | | | | | | | | | |
| (12) | Physical capital | 0.05 | 0.04 | 0.02 | 0.03 | -0.03 | -0.01 | -0.00 | -0.03 | -0.03 | 0.04 | 0.35 | 1.00 | | | | | | | | | | |
| (13) | Firm age | 0.04 | 0.04 | 0.04 | 0.01 | -0.10 | -0.01 | -0.02 | -0.09 | -0.19 | 0.20 | 0.06 | 0.04 | 1.00 | | | | | | | | | |
| (14) | R&D workers | 0.08 | 0.05 | 0.04 | 0.07 | -0.04 | -0.01 | -0.04 | -0.04 | -0.06 | 0.06 | 0.39 | 0.40 | 0.10 | 1.00 | | | | | | | | |
| (15) | University graduates | 0.09 | 0.06 | 0.05 | 0.06 | -0.04 | -0.01 | -0.01 | -0.04 | -0.04 | 0.04 | 0.56 | 0.46 | 0.10 | 0.93 | 1.00 | | | | | | | |
| (16) | R&D department | 0.38 | 0.25 | 0.23 | 0.22 | -0.08 | -0.01 | 0.01 | -0.08 | -0.17 | 0.17 | 0.06 | 0.10 | 0.07 | 0.15 | 0.16 | 1.00 | | | | | | |
| (17) | R&D intensity | 0.13 | 0.05 | 0.06 | 0.18 | -0.03 | -0.01 | 0.02 | -0.03 | -0.05 | 0.05 | -0.00 | 0.03 | -0.05 | 0.09 | 0.08 | 0.36 | 1.00 | | | | | |
| (18) | Collaboration breadth | 0.32 | 0.21 | 0.21 | 0.17 | -0.06 | -0.01 | 0.00 | -0.06 | -0.12 | 0.12 | 0.12 | 0.16 | 0.08 | 0.19 | 0.21 | 0.48 | 0.20 | 1.00 | | | | |
| (19) | Applied for patent(s) | 0.26 | 0.13 | 0.15 | 0.24 | -0.07 | -0.00 | -0.01 | -0.07 | -0.12 | 0.12 | 0.09 | 0.13 | 0.06 | 0.21 | 0.19 | 0.50 | 0.27 | 0.40 | 1.00 | | | |
| (20) | Acquired patent(s) | 0.19 | 0.11 | 0.12 | 0.13 | -0.02 | -0.00 | 0.01 | -0.02 | -0.05 | 0.05 | 0.11 | 0.15 | 0.04 | 0.17 | 0.18 | 0.29 | 0.12 | 0.27 | 0.34 | 1.00 | | |
| (21) | Sales growth | 0.01 | -0.01 | -0.01 | 0.06 | 0.03 | -0.00 | -0.00 | 0.03 | 0.06 | -0.06 | -0.01 | -0.00 | -0.02 | 0.00 | -0.00 | 0.01 | 0.05 | 0.01 | 0.03 | 0.00 | 1.00 | |
| (22) | Investment intensity | 0.06 | 0.03 | 0.03 | 0.06 | -0.00 | -0.01 | 0.02 | -0.00 | 0.03 | -0.03 | 0.00 | 0.12 | -0.03 | 0.03 | 0.03 | 0.09 | 0.20 | 0.11 | 0.10 | 0.05 | 0.02 | 1.00 |

All pairwise correlations larger than 0.014 (in absolute terms) are significant at the 5% level; the data covers years 2007-2016.

Table A.2: **Additional descriptive statistics**

| | A. 3-year average prior to 2013 | | | | | | B. 2013 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Not hiring entrepreneurs | | | Hiring entrepreneurs | | | Not hiring entrepreneurs | | | Hiring entrepreneurs | | |
| | $N$ | Mean | S.D. | $N$ | Mean | S.D. | $N$ | Mean | S.D. | $N$ | Mean | S.D. |
| Firm size | 1,343 | 111.9 | 123.1 | 908 | 461.5 | 1,485 | 1.349 | 110.0 | 113.5 | 909 | 479.2 | 1,501 |
| Physical capital (thousand DKK) | 1,343 | 147.2 | 585.3 | 908 | 702.5 | 3,945 | 1,349 | 116.6 | 442.2 | 909 | 710.9 | 4,201 |
| R&D workers (share) | 1.343 | 0.093 | 0.152 | 908 | 0.074 | 0.131 | 1.349 | 0.096 | 0.155 | 909 | 0.076 | 0.130 |
| University graduates (share) | 1.343 | 0.180 | 0.195 | 908 | 0.160 | 0.179 | 1.349 | 0.189 | 0.198 | 909 | 0.169 | 0.183 |
| New hires (share) | 1.343 | 0.194 | 0.122 | 908 | 0.260 | 0.154 | 1.349 | 0.173 | 0.121 | 909 | 0.260 | 0.156 |
| Average tenure | 1.343 | 5.358 | 2.877 | 908 | 4.099 | 2.506 | 1.349 | 5.718 | 3.001 | 909 | 4.221 | 2.533 |
| Average hourly pay (DKK) | 1.343 | 223.6 | 57.73 | 908 | 216.1 | 57.88 | 1.349 | 229.9 | 59.49 | 909 | 222.3 | 62.56 |
| Sales growth | 1.343 | 0.468 | 10.02 | 908 | 1.714 | 46.60 | 1.349 | 0.157 | 4.519 | 909 | 0.110 | 1.346 |
| Export (share) | 1.343 | 0.307 | 0.353 | 908 | 0.241 | 0.328 | 1.349 | 0.317 | 0.362 | 909 | 0.247 | 0.339 |
| Investment intensity | 1.343 | 0.039 | 0.075 | 908 | 0.039 | 0.079 | 1.349 | 0.036 | 0.081 | 909 | 0.041 | 0.094 |
| R&D intensity | 759 | 0.036 | 0.134 | 608 | 0.019 | 0.084 | 1.349 | 0.027 | 0.117 | 909 | 0.017 | 0.084 |
| Sales from innovation | 759 | 0.131 | 0.221 | 608 | 0.128 | 0.232 | 1.349 | 0.111 | 0.285 | 909 | 0.116 | 0.283 |
| ... new to the firm | 759 | 0.059 | 0.138 | 608 | 0.054 | 0.118 | 1.349 | 0.054 | 0.195 | 909 | 0.055 | 0.186 |
| ... new to the market | 759 | 0.049 | 0.124 | 608 | 0.046 | 0.128 | 1.349 | 0.043 | 0.175 | 909 | 0.050 | 0.174 |
| ... new to the world | 759 | 0.023 | 0.089 | 608 | 0.027 | 0.116 | 1,349 | 0.014 | 0.090 | 909 | 0.011 | 0.063 |
| Knowledge breadth | 759 | 4.079 | 3.400 | 608 | 4.524 | 3.564 | 1,349 | 3.660 | 4.093 | 909 | 3.836 | 4.096 |
| Collaboration breadth | 759 | 1.138 | 1.723 | 608 | 1.433 | 1.433 | 1,349 | 0.826 | 1.803 | 909 | 1.066 | 2.137 |
| Firm age | | | | | | | 1,349 | 27.48 | 18.76 | 909 | 26.41 | 18.22 |
| Copenhagen | | | | | | | 1,349 | 0.342 | 0.474 | 909 | 0.498 | 0.498 |
| University city | | | | | | | 1,349 | 0.271 | 0.444 | 909 | 0.461 | 0.461 |
| Manufacturing | | | | | | | 1,349 | 0.391 | 0.488 | 909 | 0.255 | 0.436 |
| Retail | | | | | | | 1,349 | 0.228 | 0.420 | 909 | 0.215 | 0.411 |
| Technical services | | | | | | | 1,349 | 0.110 | 0.313 | 909 | 0.079 | 0.270 |
| IT & communications | | | | | | | 1,349 | 0.079 | 0.270 | 909 | 0.098 | 0.297 |

Table A.3: **Ordinary least squares models**

| | | Model A-I: Sales from innovation | | | Model A-II: Sales from innovation | | | Model A-III: Sales from innov. new to firm | | | Model A-IV: Sales from innov. new to market | | | Model A-V: Sales from innov. new to world | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| | *Lagged employment shares* | | | | | | | | | | | | | | | |
| (1) | Hires with founder experience | 0.422 | 0.004 | 0.146 | | | | 0.275 | 0.010 | 0.107 | 0.163 | 0.054 | 0.085 | -0.017 | 0.766 | 0.056 |
| (2) | ... in *top management* | | | | -1.083 | 0.158 | 0.767 | | | | | | | | | |
| (3) | ... in *middle management* | | | | 2.123 | 0.040 | 1.034 | | | | | | | | | |
| (4) | ... in *non-management* | | | | 0.131 | 0.372 | 0.147 | | | | | | | | | |
| (5) | Hires without founder experience | -0.007 | 0.604 | 0.014 | -0.002 | 0.867 | 0.014 | -0.005 | 0.613 | 0.009 | -0.015 | 0.076 | 0.008 | 0.012 | 0.067 | 0.007 |
| | Control variables | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| | Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| | Industry-year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| | Firm fixed effects | No | | | No | | | No | | | No | | | No | | |
| | Number of observations/firms | 21,844/5,419 | | | 21,844/5,419 | | | 21,844/5,419 | | | 21,844/5,419 | | | 21,844/5,419 | | |
| | Adjusted $R^2$ | 0.185 | | | 0.185 | | | 0.086 | | | 0.072 | | | 0.085 | | |
| | *F-tests* | | | | | | | | | | | | | | | |
| | Hypothesis 1: (1)=(5) | 8.30 | 0.004 | | | | | 6.67 | 0.010 | | 4.19 | 0.041 | | 0.25 | 0.620 | |
| | Hypothesis 2: (3)=(2) | | | | 6.15 | 0.013 | | | | | | | | | | |
| | Hypothesis 2: (3)=(4) | | | | 3.63 | 0.056 | | | | | | | | | | |
| | Hypothesis 2: (3)=(2) *and* (4) | | | | 3.09 | 0.046 | | | | | | | | | | |
| | Hypothesis 3: A-III=A-IV | | | | | | | 0.71 | 0.399 | | | | | | | |
| | Hypothesis 3: A-III=A-V | | | | | | | 5.82 | 0.016 | | | | | | | |
| | Hypothesis 3: A-IV=A-V | | | | | | | 3.18 | 0.075 | | | | | | | |

Robust standard errors clustered by firm. Sample restricted to firms older than 5 years and with more than 25 employees, for years 2007-2016; stayers represent the baseline category. All models estimated by ordinary least squares (without firm fixed effects).

Table A.4: **Robustness checks**

| | Sales from innovation | | | | | | | | | | | | | | | | | | Any innov. sales | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Model A-VI: Founder + 3y | | | Model A-VII: Founder – 2y | | | Model A-VIII: Direct hires | | | Model A-IX: Leads | | | Model A-X: Stocks | | | Model A-XI: Tobit | | | Model A-XII: Founder | | |
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Lagged employment shares* | | | | | | | | | | | | | | | | | | | | | |
| Hires w/ founder exp. | 0.396 | 0.019 | 0.169 | 0.387 | 0.095 | 0.232 | 0.637 | 0.025 | 0.284 | 0.070 | 0.719 | 0.196 | 0.370 | 0.052 | 0.190 | 1.845 | 0.008 | 0.698 | 0.032 | 0.902 | 0.261 |
| Hires w/o founder exp. | -0.007 | 0.708 | 0.020 | -0.003 | 0.898 | 0.020 | -0.001 | 0.963 | 0.020 | -0.005 | 0.828 | 0.024 | | | | -0.113 | 0.115 | 0.072 | -0.053 | 0.070 | 0.029 |
| Control variables | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| Sales growth/investment | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| Industry-year FEs | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| Firm fixed FEs | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | No | | | Yes | | |
| Number of obs./firms | 20,271/3,846 | | | 20,271/3,846 | | | 20,271/3,846 | | | 17,649/3,599 | | | 20,271/3,846 | | | 21,844/5,419 | | | 20,271/3,846 | | |
| Adjusted $R^2$ | 0.310 | | | 0.310 | | | 0.310 | | | 0.308 | | | 0.310 | | | | | | 0.490 | | |

Robust standard errors clustered by firm, OLS FE models (except in Model A-XI). Sample restricted to firms older than 5 years and with more than 25 employees, for years 2007-2016; stayers represent the baseline category, except in Model A-X, where we include the stock of workers with founder experience.

Table A.5: **Middle management hires: entrepreneurs vs. non-entrepreneurs**

| | | Model A-XIII: Sales from innovation | | | Model A-XIV: Sales from innov. new to firm | | | Model A-XV: Sales from innov. new to market | | | Model A-XVI: Sales from innov. new to world | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| | *Lagged employment shares* | | | | | | | | | | | | |
| | Hires with founder experience | | | | | | | | | | | | |
| (1) | ... in *top management* | -2.058 | 0.130 | 1.359 | -1.069 | 0.309 | 1.051 | -1.067 | 0.087 | 0.624 | 0.077 | 0.665 | 0.179 |
| (2) | ... in *middle management* | 2.616 | 0.054 | 1.358 | 2.332 | 0.038 | 1.123 | 0.480 | 0.532 | 0.767 | -0.196 | 0.711 | 0.528 |
| (3) | ... in *non-management* | 0.235 | 0.225 | 0.194 | 0.241 | 0.087 | 0.141 | -0.065 | 0.589 | 0.120 | 0.059 | 0.414 | 0.072 |
| | Hires without founder experience | | | | | | | | | | | | |
| (4) | ... in *top management* | -0.152 | 0.560 | 0.261 | -0.105 | 0.568 | 0.184 | 0.027 | 0.848 | 0.140 | -0.073 | 0.371 | 0.082 |
| (5) | ... in *middle management* | 0.076 | 0.637 | 0.160 | -0.176 | 0.137 | 0.118 | 0.158 | 0.114 | 0.100 | 0.094 | 0.190 | 0.072 |
| (6) | ... in *non-management* | -0.003 | 0.877 | 0.020 | 0.013 | 0.353 | 0.014 | -0.021 | 0.073 | 0.012 | 0.004 | 0.611 | 0.008 |
| | Control variables | Yes | | | Yes | | | Yes | | | Yes | | |
| | Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | |
| | Industry-year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| | Firm fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| | Number of observations/firms | 20,271/3,846 | | | 20,271/3,846 | | | 20,271/3,846 | | | 20,271/3,846 | | |
| | Adjusted $R^2$ | 0.310 | | | 0.199 | | | 0.206 | | | 0.267 | | |
| | *F-tests* | | | | | | | | | | | | |
| | (2)=(5) | 3.51 | 0.061 | | 4.95 | 0.026 | | 0.17 | 0.676 | | 0.30 | 0.583 | |

Robust standard errors clustered by firm. Sample restricted to firms older than 5 years and with more than 25 employees, for years 2007-2016; stayers represent the baseline category. All models estimated by ordinary least squares with firm fixed effects.

Table A.6: **The role of acquihires**

| | Sales from innovation | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Model A-XVII: Disaggregating new hires (focal founders) | | | Model A-XVIII: Disaggregating new hires (any founders) | | | Model A-XIX: Excluding acquihires (focal founders) | | | Model A-XX: Excluding acquihires (any founders) | | |
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Lagged employment shares* | | | | | | | | | | | | |
| Hires with founder experience | | | | | | | 0.590 | 0.002 | 0.193 | 0.631 | 0.001 | 0.195 |
| ... outside acquihires | 0.575 | 0.002 | 0.186 | 0.593 | 0.002 | 0.187 | | | | | | |
| ... within acquihires | -1.000 | 0.072 | 0.555 | -1.193 | 0.040 | 0.581 | | | | | | |
| Hires without founder experience | -0.008 | 0.701 | 0.020 | -0.007 | 0.737 | 0.020 | -0.006 | 0.773 | 0.020 | -0.009 | 0.675 | 0.021 |
| Control variables | Yes | | | Yes | | | Yes | | | Yes | | |
| Sales growth/investment | Yes | | | Yes | | | Yes | | | Yes | | |
| Industry-year FEs | Yes | | | Yes | | | Yes | | | Yes | | |
| Firm fixed FEs | Yes | | | Yes | | | Yes | | | Yes | | |
| Number of obs./firms | 20,271/3,846 | | | 20,271/3,846 | | | 19,653/3,754 | | | 19,182/3,687 | | |
| Adjusted $R^2$ | 0.310 | | | 0.310 | | | 0.309 | | | 0.310 | | |

Robust standard errors clustered by firm. Sample restricted to firms older than 5 years and with more than 25 employees, for years 2007-2016. Models A-XVII and A-XIX focus on focal founders of acquired firms, while models A-XVIII and A-XX focus on all former founders in acquired firms. In models A-XIX and A-XX, we exclude firm observations with acquihires in the year prior to the focal year. All models estimated by ordinary least squares with firm fixed effects.

Table A.7: **Direct hires with different prior experience**

| | | Model A-XXI: Sales from innovation | | | Model A-XXII: Sales from innov. new to firm | | | Model A-XXIII: Sales from innov. new to market | | | Model A-XXIV: Sales from innov. new to world | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| | *Lagged employment shares* | | | | | | | | | | | | |
| (1) | Hires with founder experience | 0.655 | 0.021 | 0.284 | 0.360 | 0.060 | 0.192 | 0.348 | 0.063 | 0.187 | -0.053 | 0.535 | 0.085 |
| (2) | Hires with management experience | 0.163 | 0.330 | 0.168 | 0.228 | 0.047 | 0.115 | 0.008 | 0.935 | 0.104 | -0.073 | 0.190 | 0.056 |
| (3) | Hires with sales experience | -0.057 | 0.270 | 0.051 | -0.041 | 0.310 | 0.040 | -0.004 | 0.904 | 0.033 | -0.012 | 0.497 | 0.018 |
| (4) | Hires with R&D experience | 0.055 | 0.637 | 0.117 | 0.000 | 0.997 | 0.075 | 0.030 | 0.617 | 0.060 | 0.025 | 0.698 | 0.065 |
| (5) | Hires with other experience | -0.005 | 0.830 | 0.025 | 0.010 | 0.593 | 0.018 | -0.028 | 0.031 | 0.013 | 0.013 | 0.219 | 0.011 |
| | Control variables | Yes | | | Yes | | | Yes | | | Yes | | |
| | Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | |
| | Industry-year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| | Firm fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| | Number of observations/firms | 20,271/3,846 | | | 20,271/3,846 | | | 20,271/3,846 | | | 20,271/3,846 | | |
| | Adjusted $R^2$ | 0.310 | | | 0.198 | | | 0.206 | | | 0.267 | | |
| | *F-tests* | | | | | | | | | | | | |
| | (1)=(2) | 2.24 | 0.134 | | 0.38 | 0.540 | | 2.55 | 0.110 | | 0.04 | 0.846 | |
| | (1)=(3) | 5.93 | 0.015 | | 4.08 | 0.043 | | 3.30 | 0.069 | | 0.21 | 0.644 | |
| | (1)=(4) | 3.77 | 0.052 | | 2.93 | 0.087 | | 2.68 | 0.102 | | 0.49 | 0.482 | |
| | (1)=(5) | 5.33 | 0.021 | | 3.30 | 0.069 | | 4.01 | 0.045 | | 0.60 | 0.439 | |

Robust standard errors clustered by firm. Sample restricted to firms older than 5 years and with more than 25 employees, for years 2007-2016; stayers represent the baseline category. Prior experience refers only to the year prior to the hiring event (i.e. 'direct hires'). All models estimated by ordinary least squares with firm fixed effects.

# Chapter 2: **The Role of Research Equipment for Firm Innovation**

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## 2.1 Introduction

The innovation literature has paid substantial attention to human capital as a major determinant of firms' innovation performance (Song, Almeida and Wu, 2003; Singh and Agrawal, 2011; Kaiser et al., 2018). There is no doubt that creating new solutions and taking them to market is a knowledge intensive process requiring highly skilled human capital (Grant, 1996; Kogut & Zander, 1992). For firms to capitalize on their scientific human capital, they must provide their R&D workers which research equipment such as high-throughput screening machines, gene sequencers, and specialized instruments to perform their tasks (Stephan & Levin, 1992). The role of this specific type of physical capital for innovation has been largely overlooked in the innovation literature both theoretically and empirically.

As opposed to human capital which has free will and take their knowledge with them if they leave to competing firms (Agarwal et al., 2016; Coff, 1997), physical capital can be fully appropriated and controlled by the possessing firm. Following this logic, physical capital should be relatively more attractive to human capital as a means to improve sustained competitive advantage especially in settings where retaining highly skilled human capital is challenging. However, when it comes to research and development for firm innovation, human capital in the form of R&D workers and physical capital in the form of research equipment has no value if not both are present. Therefore, the source of competitive advantage may lie in striking the balance between human capital and physical capital spendings.

A key decision for corporate R&D managers is how to allocate the R&D budget, for instance, across internal and external R&D (Berchicci, 2013; Cassiman & Veugelers, 2006; Grimpe & Kaiser, 2010; Hagedoorn & Wang, 2012) as well as basic and applied research (Mansfield, 1980; Rosenberg, 1989; Czarnitzki and Thorwarth, 2012). To the best of our knowledge, this study is the first to investigate the balance between human capital and physical capital when it comes to internal R&D as well as the first large scale empirical evidence of the role of research equipment for firms' innnovation performance. Internal R&D is often viewed as a determinant firms' innovation potential (Berchicci, 2013; Hagedoorn & Wang, 2012) and absorptive capacity (Cohen & Levinthal, 1990; Fabrizio, 2009) but with little notion of how R&D resources are spend.

Following arguments from the economics of science literature (Baruffaldi & Gaessler, 2021; Dasgupta & David, 1994; Ding et al., 2010; Furman & Teodoridis, 2020; Stephan, 1996, 2012), we propose that R&D investments into research equipment increase productivity of firms' scientific human capital through optimization and redirection of attention and ultimately increases innovation performance. In addition to improving R&D workers productivity, we argue that investments in research equipment improve firms' ability to attract and retain highly skilled human capital with the prospect of working with cutting-edge research tools.

We theorize that the relationship between research equipment and innovation follows an inverted u-shape. We predict that increased spending on research equipment increases firms' innovation performance up until a certain point of diminishing returns to adding more equipment and eventually becomes negative due to the trade-off with spending on human capital as well as potential path dependencies from overinvesting in specific equipment (Dosi, 1982; Teece, 1986). We find empirical evidence for these predictions and show that investment into research equipment is associated with more PhD-researcher intensive R&D teams in line with the argument the research equipment improves firms' ability to attract and retain highly skilled human capital. We also find that there is no effect of increasing spending on research equipment for large firms and firms who are industry leaders in terms of innovation. These findings speak to the diminishing returns of additional research equipment but may also indicate that investing in research equipment is a viable strategy for industry laggards and smaller firms who may have a hard time attracting highly skilled human capital. In further support for the argument that research equipment improves innovation performance through attraction and retention of highly skilled human capital and is more attractive in settings where employees are prone to leave and take their knowledge with them, we show that increased equipment spending matters only in industries with high employee turnover.

The empirical analysis is based on the Danish version of the Community Innovation Survey (CIS) coupled with employer-employee linked labor market data (IDA) providing a representative panel of R&D active firms. Research equipment is measured as R&D expenditures spend on equipment as a share of total R&D spending where salaries and other expenditures related to human capital is the major component. Following previous innovation literature, performance is measured as sales from new products and R&D workers are identified as individuals with a degree in a STEM related field occupying a knowledge intensive position in the focal firm following the approach by Kaiser et al. (2015). As predicted, we find an inverted u-shaped relationship between research equipment and innovation, but that the majority of firms in our sample invest far below the infliction point. In light of these positive results as well the attractive features of physical capital when it comes to appropriability, there seems to be substantial potential for firms to intensify their spending on research equipment.

The paper is structured in a theory section reviewing relevant literature, a data section and a method section accounting for the empirical setting and challenges, a results section presenting main estimations followed by robustness and heterogeneity analyses. Finally, results and limitation are discussed before reaching concluding remarks.

## 2.2 Theory

Research equipment is an essential part of the infrastructure in the research and development process (Stephan & Levin, 1992; Stephan, 1996, 2012). Equipment for R&D includes specialized lab instruments as well as larger machines such as high-throughput screeners and gene sequencers.

In this section, we rely on insights from human capital theory, economics of science literature, and innovation literature to build arguments of why research equipment is a distinct source of innovation performance.

### 2.2.1 Human and Physical Capital

While the role of human capital has been rightfully emphasized for the production of knowledge and development of innovation (Azoulay et al., 2010; Bogers et al., 2018; Kaiser et al., 2018; Kehoe & Tzabbar, 2015; Laursen et al., 2020; Østergaard et al., 2011; Song et al., 2003), physical capital also plays an important and potentially overlooked role. In fact, new knowledge is a result of a highly (physical) capital-intensive process (Stephan, 2012). R&D scientists and technicians need instruments and tools for tasks such as experimenting and testing. In fields such as biomedicine, researchers reside in highly specialized laboratories with a diverse range of equipment at their disposal (Latour & Woolgar, 2013). As such, human capital and physical capital are complements as both types of inputs are needed in the innovation process. Labor-capital substation effects might occur as routine tasks performed by R&D workers are performed or optimized by machines (Furman & Teodoridis, 2020).

R&D managers are typically faced with a fixed budget which they have to allocate across R&D salaries and R&D equipment the two main cost drivers of the R&D process. From a strategic perspective the two types of capital inputs hold distinct advantages and disadvantages. Human capital can be adjusted through the hiring and firing of individuals and these individuals can independently affect the rate and direction of technological discovery (Campbell et al., 2012; Coff, 1997). Physical capital on the other hand, is more fixed such that overinvestment in physical capital may lead to path dependencies (Dosi, 1982; Teece, 1986) and myopia (Levinthal & March, 1993; Maskell & Malmberg, 2007) as existing research tasks become optimized and labor-capital specialization is tied to specific equipment such that deviations into new technological paths comes at a high cost.

In terms of competitive advantage, physical capital enjoys the advantage over human capital which has free will and can move to rival firms with substantial knowledge spillovers (Agarwal et al., 2016; Coff, 1997), that it can be fully appropriated and controlled by the possessing firm. In settings with high labor mobility, increasing equipment spending intensity may be an attractive avenue for firms in order to appropriate a large share of the value from its internal R&D activities. Furthermore, the fact that human capital has free will also implies that individuals can choose to join or leave a firm based on the attractiveness of the firm as an employer. Since R&D activities are a capital-intensive process often requiring and array of tools and machinery, it is likely that the decision of individuals to join and stay with a firm is influenced by the availability of high-quality research equipment.

Individuals are unique and in R&D intensive sectors there is a scarcity of highly skilled human capital (Beechler & Woodward, 2009; Consoli & Elche, 2014; Elving et al., 2013). Human capital is a source of competitive advantage as the specialized knowledge intensive human capital of R&D workers may not easily be imitated or substituted (Barney, 1991; Wernerfelt, 1984). Research equipment, on the other hand, may be readily available on the market for firms to purchase such that research equipment is not a source of competitive advantage in itself but rather the co-specialization of firms' human and physical capital as well as the ability to strike the right balance between spendings across the two capital inputs brings competitive advantage.

### 2.2.2 Research Equipment and Science

While the innovation literature is largely silent about the role of research equipment for innovation, the economics of science literature lends interesting insights on relationship between equipment and scientific knowledge production. In a recent study of technology adoption, Furman and Teodoridis (2020) explore the effect of a suddenly available motion-sensing technology that automates research tasks within the areas of Computer Science and Electrical engineering. The authors finds that the automation technology not only increased the number of ideas produced by scientists but also leads to ideas that were more distinct from the researchers' existing trajectories. These findings suggest that the introduction of new research equipment may not only enable more innovation but also change direction towards more radical innovation as researchers are tied away from routine tasks.

Waldinger (2016) uses the abrupt loss of physical and human capital during World War II to show that loss of both types of capital has negative effects on the production of knowledge though these persist more long-term for the loss of human capital compared to physical capital. These findings suggest, in line with our arguments above, that physical capital is more replaceable than human capital and, thus, may not be a source of competitive advantage in itself (Barney, 1991; Wernerfelt, 1984). Baruffaldi and Gaessler (2021) document decreases in the knowledge production of academic scientist following loss of physical capital caused by destruction of labs due to adverse events such as earthquakes. The authors find that negative effects of loss of research equipment on productivity of affected researchers is long-lasting and argue that this is due to a high degree of specialization of the research equipment such that researchers cannot recover their productivity by acquiring equipment on the market. The economics of science literature gives us clear indications of the important role of research equipment for knowledge production which is a central antecedent for innovation.

### 2.2.3 Research Equipment and Innovation

Research and development practices in technology-oriented firms oftentimes resemble research in academic science in which scientists and engineers require tools and instruments to conduct experiments, create designs, and assemble prototypes (Dasgupta and David, 1994), lending findings from the economics of science literature relevant to our setting of industrial innovation. Yet, the relationship between research equipment and firm innovation is distinct from scientific knowledge production when it comes to the degree of researcher-equipment specialization. Equipment for scientific knowledge production tends to be highly specialized and its value is to a large extent tied to individual researchers or research teams (Baruffaldi & Gaessler, 2021).

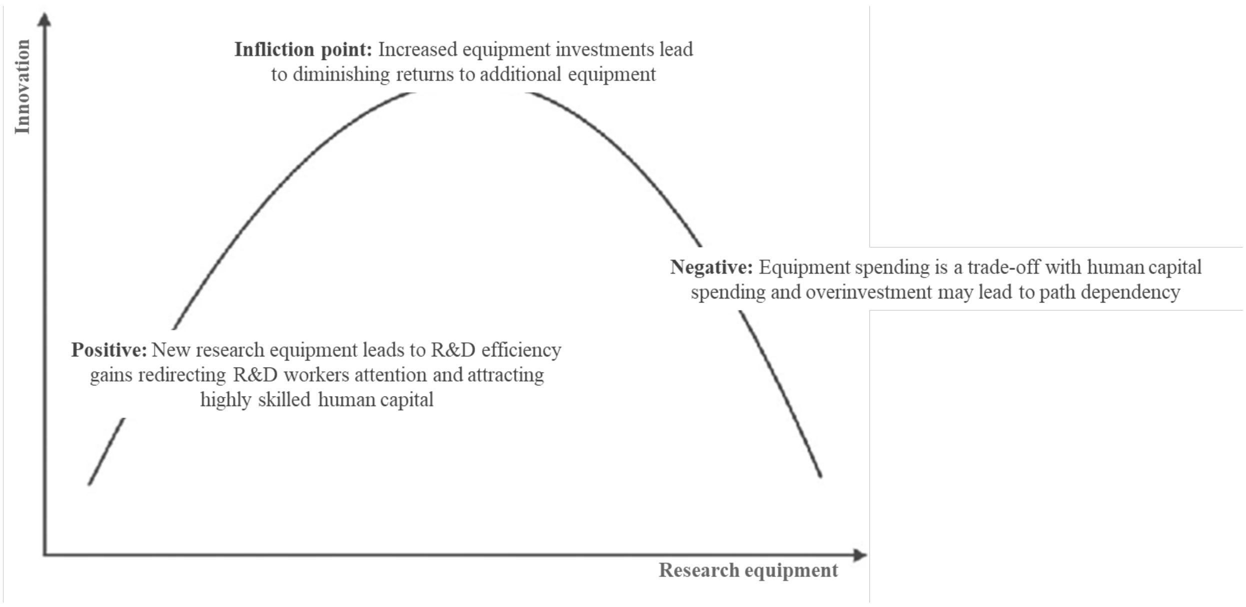
In the setting of industrial research and development, we assume a lesser degree of researcher specialization of equipment as industrial research is driven to a greater extent by applied and developmental research as opposed to academic research (Mansfield, 1980; Czarnitzki and Thorwarth, 2012). Furthermore, the higher level of financial resources available to firms as compared to universities may create a market for specialized equipment for industrial application. Yet, if research equipment is readily available on the market for firms to purchase it may not be a source of competitive advantage (Wernerfelt, 1984). However, we simply argue that the procurement of research equipment is an immediate enabler of industrial knowledge creation and innovation, but a sustained competitive advantage may arise from some degree of co-specialization of firms' human capital and physical capital. As R&D budgets are often constrained, the ability of firms to strike the optimal balance between equipment spending and other R&D spendings may be an important source of competitive advantage for innovative firms.

In this respect, firms typically have a choice regarding whether to procure the latest equipment or not. Nightingale (2000) provides anecdotal evidence that new research tools had a tremendous impact on pharmaceutical research productivity. The adoption of high-throughput screening devices allowed for the systematic and fast testing of new molecule combinations, yielding a drastic improvement in this particular R&D task. Such increases of productivity in certain tasks may allow for re-direction of researchers' attentions to other more knowledge intensive tasks such as research and development of more radically novel ideas (Furman & Teodoridis, 2020).

### 2.2.4 Non-linear Relationship between Research Equipment and Firm Innovation

Research equipment may enable firm innovation by increasing efficiency of R&D tasks redirecting R&D employees' attention to other more value-creating tasks or enable them to perform entirely new tasks which may spur radically novel ideas. Together with increased ability to attract and retain highly skilled human capital we theorize a positive yet non-linear relationship between research equipment and innovation. An inverted u-shaped relationship with increasing returns to equipment investment followed by diminishing and negative returns may arise for three reasons. In economic terms, increasing investment in research equipment may diminish the return to adding an additional unit of equipment at high levels of investment. R&D budgets are assumed to be limited implying the overinvestment in physical capital compromises spending on human capital with adverse effects for innovation performance. Finally, overinvestment in R&D may lead to path dependency and myopia further arguing for a negative effect at spending high levels.

**Figure 1: Inverted U-shape for Equipment and Innovation**



## 2.3 Data

Our empirical setting, Denmark, has two key advantages for the purpose of this study. First, the Danish economy is to a large extent driven by export of R&D intensive products such as pharmaceuticals, green tech, and chemicals. A setting with many globally innovative companies allows us to obtain a large and representative sample of R&D intensive firms. Second, the ability to link both firm-level and individual-level data from multiple sources through the national statistics agency, Statistics Denmark, provides a rich dataset to tackle heterogeneity and endogeneity concerns related to investments into R&D and firm innovation.

### 2.3.1 Community Innovation Survey

The key variables in this study are obtained from the Community Innovation Survey (CIS). Based on the OECD Oslo Manual for collecting and reporting innovation data, this dataset is the main source of innovation information for European firms. The Danish version of the survey covers approximately 4,500 firms per year. The sample is randomly stratified across industries and likelihood of being in the sample increases with firm size and R&D intensity such that the largest and most R&D active firms (~500 firms) participate every year with most firms participating multiple times in our panel. Variables related to innovation are available on a yearly basis from 2007 and onwards while R&D related variables can be observed further back.

### 2.3.2 Integrated Labor Market Data

The community innovation survey data is linked to a general firm register containing financial and legal information on all firms in Denmark providing measures such as firm sales, size, age, ownership, and assets. The dataset is linked to Integrated Database for Labor Market Research (IDA) combined with other registers containing International Standard Classification of

Occupations (ISCO) codes and educational codes. This individual level information is used to identify R&D employees and their educational backgrounds before aggregating to firm-level.

### 2.3.3 Dependent Variables

To estimate the association between research equipment and innovation performance we rely on sales from innovation as a classical measure of firm innovation (Cassiman & Veugelers, 2006; Klingebiel & Rammer, 2014; Laursen & Salter, 2006; Leiponen & Helfat, 2010) In practice, we use the natural logarithm of *sales from innovation.* This variable is generated by multiplying share of sales from innovation reported in CIS with firm sales from the general firm register. To access whether research equipment has a differentiated effect on incremental and radical innovation, we disaggregate the variable into sales from innovation *new to the firm* and sales from innovation *new to the market* representing incremental and radical innovation respectively (Laursen & Salter, 2006).

To assess our theoretical prediction that research equipment improves efficiency of firms' human capital we compute a measure of *R&D labor productivity* which is given by sales from innovation over number of R&D workers. Using the approach by Kaiser et al., (2015), R&D workers are identified based on individuals' educational background and position in the organization hierarchy of the focal firm. First criterion is that the individual has a higher degree (undergraduate, graduate, or postgraduate degree) in a STEM related field (technical, natural, veterinary, agricultural, and health sciences). Second, the individual must perform a job function inside the focal firm involving the use or production of advanced knowledge. Job functions are observed by linking data to a database containing International Standard Classification of Occupations (ISCO). At the 1-digit level, these codes classify employees in job functions requiring entry-level knowledge (level 4), intermediate-level knowledge (level 3), high-level knowledge (level 2) and managers (level 1). Intermediate- and high-level functions corresponds to associate professionals and professionals respectively. R&D professionals represent scientists while R&D associate professionals represent technicians. We asses another mechanisms for the positive association between research equipment and innovation, that is, increased ability to attract and retain highly skilled human capital. To investigate this argument empirically, we look at the labor composition of firms R&D workers following R&D equipment investments to see if the composition of technicians, researchers with PhD degree and researchers without PhD degree changes.

### 2.3.4 Independent Variables

The main independent variable is the share of R&D spending devoted to *research equipment*. This variable comes from the Community Innovation Survey where R&D managers or equivalent are asked to report total R&D spending on four different categories: (1) salary and other expenses related to R&D employees, (2) other operational expenses, (3) R&D buildings, and (4) R&D equipment. Spendings on salary and other expenditures related to human capital is by far the largest cost driver of corporate internal R&D wile R&D equipment is the second largest cost driver. Though expenditures for buildings is a form of physical capital, we do not include these because buildings are not expected to directly affect productivity as R&D workers do not interact with buildings like they interact with research equipment. Results, however, are robust to the inclusion of expenditures for buildings, such that findings may be extended to general physical capital rather than restricted to research equipment. To investigate the potential non-linear relationship between research equipment and innovation, we include the *squared term* of share of R&D spend on equipment. In robustness checks, a three-year average of the independent variables are used instead of yearly spending as firms may make large equipment investments in one year and no investments in other.

### 2.3.5 Control Variables

We control for multiple variables which may co-determine equipment spending and firm innovation. Controls include *firm size* as measured by number of employees (including only those having their main occupation with the firm), *firm age* measured as years since establishment of the firm as a legal entity, *physical capital* given by the natural logarithm of the book value of firms' fixed assets. The natural logarithm of number of *R&D workers* and *university graduates* are included to control for firms' scientific as well as general human capital. R&D expenditures normalized by revenue are included as a control for *R&D intensity.* Dummies for whether the firm is *publicly traded* and located in the *Capital* region are included. Finally, we control for two lags of sales growth and investment intensity as measures of investment opportunity and actual investments (Bloom et al., 2007; Michaely & Roberts, 2012). NACE 2-digit industry and year dummies are included in all models along with firm fixed effects. All input variables are lagged by one year.

### 2.3.6 Sample

Our analysis sample is restricted to firms participating in the Community Innovation Survey (approximately 4,500 per year). The main dependent variable, innovation sales, can be tracked consistently from 2007 and onwards and we have access to the CIS data until and including year 2016. Our sample is further restricted to firms with R&D expenditures because the main independent variable, share of R&D spend on equipment, can only be computed for firms with R&D expenditures. Firms with less than ten employees are excluded to make the sample comparable to other CIS samples which usually sample firms above this size. For main specifications, we are left with 6,534 firm-year observations and 1,416 unique firm observations from 2007-2016. The sample is representative of R&D active firms.

### 2.3.7 Descriptive Statistics

Firms in our sample have on average 15 percent of their total sales coming from new products highlighting that the majority of our firms are innovation active. Out of total innovation sales, 6.6 percent stems from innovation new to the firm, while 8.3 percent is from innovation new to the market reflecting that we have a sample of globally innovative firms. For the average firm, 2.1 percent of their R&D workforce have a PhD degree. Firms spend, on average, 5 percent of their R&D budget on research equipment. Driven by the intensified sampling of large R&D intensive firms in CIS, the average firm in our sample is with 335 employees relatively large compared to the population of Danish firms. Firms employ 57 R&D workers and 87 university graduates. Share of revenue spend on R&D is 0.37 although this high share is driven by a few outliers. 84 percent of our sample are publicly traded companies while 39 percent are located the area of Copenhagen which is capital region of Denmark.

Table 1: **Descriptive statistics for main variables**

| | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| *Share of sales from innovation* | | | | |
| Sales from innovation | 0.150 | 0.308 | 0 | 1 |
| Sales from innovation new to firm | 0.066 | 0.195 | 0 | 1 |
| Sales from innovation new to market | 0.083 | 0.229 | 0 | 1 |
| *Sales from innovation* | | | | |
| Sales from innovation (thousand DKK) | 100,750.7 | 1,216,973 | 0 | >37,200,000 |
| Sales from innovation new to firm (thousand DKK) | 72,271.58 | 690,276.8 | 0 | >37,200,000 |
| Sales from innovation new to market (thousand DKK) | 88,623.93 | 615,928.3 | 0 | >21,100,000 |
| *PhD Researchers* | | | | |
| Share of R&D workers w. PhD degree | 0.021 | 0.085 | 0 | 1 |
| *Research equipment* | | | | |
| Share of R&D spend on equipment | 0.046 | 0.122 | 0 | 1 |
| *Control Variables* | | | | |
| Firm size | 335.169 | 1079.399 | 10 | >23,000 |
| Firm age | 25.670 | 18.879 | 3 | >130 |
| Physical capital (thousand DKK) | 674.564.4 | 3,268,642 | 0 | >66,000,000 |
| R&D workers | 56.764 | 235.675 | 0 | >7,000 |
| University graduates | 87.267 | 298.313 | 0 | >8,000 |
| R&D intensity | 0.367 | 6.300 | 0 | >300 |
| Publicly traded firm dummy | 0.835 | 0.371 | 0 | 1 |
| Capital region dummy | 0.386 | 0.487 | 0 | 1 |
| Sales growth | 0.297 | 6.360 | -1 | >300 |
| Investment intensity | 0.040 | 0.104 | 0 | 1 |
| *Largest sectors* | | | | |
| Manufacturing | 0.522 | 0.500 | 0 | 1 |
| Technical services | 0.141 | 0.348 | 0 | 1 |
| IT & Communications | 0.185 | 0.388 | 0 | 1 |

## 2.4 Method

### 2.4.1 Identification Challenges

A natural concern for this study is the presence of endogeneity, i.e., unobserved factors that are co-determining investments in R&D equipment and innovation outcomes. Better and more innovative firms may make better investment decisions when it comes to research equipment. The inclusion of firm-fixed is important in alleviating the concern that fundamentally better firms make better investment decisions. A second concern is that firms who are already on an upward trend in terms of innovation performance invest more in research equipment due to expectations of increasing innovation output. The endogenous choice of managers to invest in equipment may correlate with other strategic decisions which enable innovation such as devoting more resources to innovation in general [15]. To alleviate the concern that procuring equipment is a specific event tied to the expectation of forthcoming innovation, we rerun models with three-year averages of equipment spending. In a separate set of models, three-year averages of innovation output and inputs in years prior to R&D investment are ran to address the concern that results might be driven by past innovation performance.

### 2.4.2 Estimation

We regress logged sales from innovation on share of R&D spend on research equipment along with a squared term and a rich set of controls including lags of investment intensity and firm growth. All models are run with year, industry, and firm fixed effects. Given that we observe firms repeatedly over time, standard errors are clustered at the firm-level in all econometric specifications. As current output is a function of past input and to alleviate concerns of reverse causality, all input variables are lagged by one year.

[15] For future versions of this manuscript, we will include an instrumental variable in the form of exogenous variation which affect the decision to invest in research equipment but not innovation outcomes. Specifically, we will look into wage shocks which would make human capital inputs relatively more expensive to physical capital inputs for some firms but not others as well as constraints on monetary capital for investment.

## 2.5 Results

### 2.5.1 Main Results

Table 2 displays the results of regressing sales from innovation on share of R&D spend on equipment and a standard set of controls. Model I shows that, in line with our theoretical expectation, research equipment is positively and significantly associated to sales from innovation with a negative and significant squared term in support of the u-shaped relationship between equipment and innovation. The positive association between research equipment and innovation is stronger for innovation of higher novelty as per model II and model III. F-tests comparing coefficients across the two models[16] shows that the beta coefficients for research equipment in models II and III are significantly different indicating a differentiated and stronger effect of research equipment on radical rather than incremental innovation. These results support the notion that research equipment ties up researchers' attention from routine tasks in redirect them to more knowledge intensive tasks. Model IV displays the result of regressing innovation sales per R&D employee as a measure of innovation productivity on equipment spending. Similar to model I, share of research equipment is associated with innovation productivity first in an increasing then descending relationship supporting the idea that research equipment increases efficiency of routine R&D tasks enabling corporate researchers to spend their time more productively.

Looking at control variables, one might be surprised to see that R&D workers and R&D intensity are insignificant and sometimes even negative. This is often the case when sales from innovation is the dependent variable. R&D intensive firms such as pharmaceutical companies invest lot in R&D but often the majority of their revenue comes from cash-cow drugs.

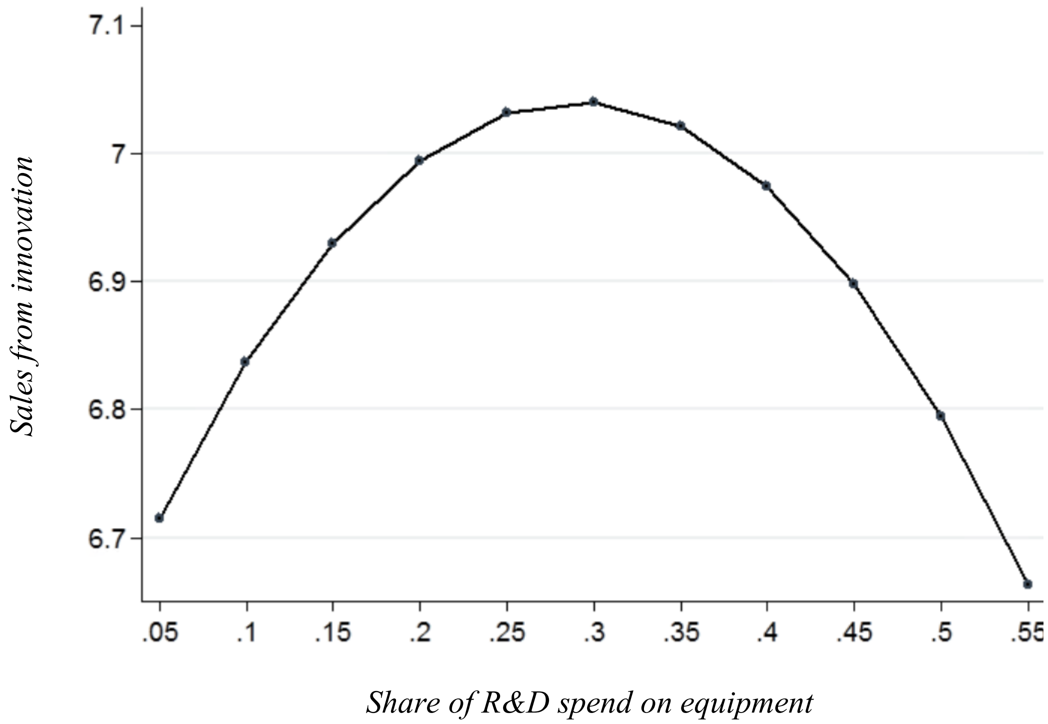
[16] Models with firm fixed effects do not lend themselves well to testing of coefficients across models. Hence, F-tests are carried out on models without firm fixed effects displayed in table A.1 These models are consistent with main models.

Table 2: **The effect of research equipment on firms' sales from innovation**

| | Model I: Sales from innovation | | | Model II: Sales from innov. new to firm | | | Model III: Sales from innov. new to market | | | Model IV: Innovation productivity | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Research equipment* | | | | | | | | | | | | |
| Share R&D equipment | 3.261 | 0.037 | 1.560 | 3.335 | 0.055 | 1.737 | 4.521 | 0.006 | 1.652 | 2.621 | 0.049 | 1.328 |
| Share R&D equipment sq. | -5.606 | 0.033 | 2.632 | -5.869 | 0.035 | 2.783 | -7.427 | 0.005 | 2.639 | -4.608 | 0.053 | 2.384 |
| Log Firm size | -0.000 | 0.727 | 0.000 | -0.000 | 0.727 | 0.000 | 0.000 | 0.828 | 0.000 | -0.000 | 0.718 | 0.000 |
| Log Physical capital | 0.035 | 0.689 | 0.088 | 0.049 | 0.553 | 0.082 | 0.028 | 0.745 | 0.085 | 0.030 | 0.675 | 0.073 |
| Firm age | 0.020 | 0.000 | 0.004 | 0.023 | 0.000 | 0.005 | 0.020 | 0.000 | 0.005 | 0.018 | 0.000 | 0.003 |
| Log R&D workers | 0.380 | 0.189 | 0.289 | 0.435 | 0.145 | 0.298 | -0.081 | 0.780 | 0.290 | 0.069 | 0.805 | 0.277 |
| Log University graduates | -0.003 | 0.993 | 0.392 | -0.279 | 0.471 | 0.387 | 0.209 | 0.573 | 0.371 | -0.172 | 0.651 | 0.370 |
| R&D intensity | 0.005 | 0.602 | 0.010 | -0.015 | 0.008 | 0.006 | 0.004 | 0.738 | 0.011 | 0.010 | 0.470 | 0.014 |
| Publicly traded dummy | 0.917 | 0.126 | 0.599 | -0.316 | 0.650 | 0.697 | 1.150 | 0.112 | 0.724 | 0.755 | 0.104 | 0.464 |
| Capital region dummy | -0.414 | 0.710 | 1.116 | -0.333 | 0.767 | 1.123 | -0.153 | 0.906 | 1.298 | -0.202 | 0.824 | 0.909 |
| Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | |
| Industry fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Firm fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Number of observations/firms | 6,534/1,416 | | | 6,534/1,416 | | | 6,534/1,416 | | | 6,095/1,288 | | |
| Adjusted $R^2$ | 0.381 | | | 0.312 | | | 0.367 | | | 0.358 | | |
| *F-tests* | | | | | | | | | | | | |
| Equipment for new to firm vs. new to market: Model II=III | | | | 3.09 | 0.079 | | | | | | | |
| Equipment squared for new to firm vs. new to market: Model II=III | | | | 4.32 | 0.038 | | | | | | | |

Robust standard errors clustered by firm. Sample restricted to firms with 10 or more employees for years 2007-2016. All models estimated by ordinary least squares with firm fixed effects. Innovation is measured as total sales from innovation. Innovation productivity as measured as sales from innovation per R&D employee. F-tests across models are based on OLS models without FE displyed in appendix A.2 along with Tobit estimations.

**Figure 2: Research Equipment and Firm Innovation**




Plotting predicted marginal effects; the graph clearly demonstrates an inverted u-shape. Figure 1 shows that research equipment is positively associated with sales from innovation up until 30 percent of the R&D budget spend on research equipment. Though keeping in mind that this effect cannot be treated as causal, it is interesting that 95 percent of our sample appear to devote a smaller share of their R&D budget to equipment than estimates suggest as the optimum. In sum, we find strong support for our prediction that the association between research equipment and innovation follows and inverted u-shape and with the interesting finding that only 5 percent of firms invest above the infliction point.

### 2.5.2 Additional Analyses

In addition to improving efficiency of R&D employees, we suggest that new research equipment improves firms' ability to attract and retain highly skilled human capital. This mechanism is explored in table 3 where model V displays a positive non-linear relationship between equipment investments and the share of R&D workers with a PhD degree. This implies that firms spending more on research equipment move towards more PhD intensive research teams in support of the argument that cutting-edge research equipment helps firm attract and retain highly skilled human capital. We also explore potential capital-labor substitution effects. If research equipment automates routine R&D tasks, we would expect to see substitution mainly at the technician-level rather scientists-level. We find no evidence of such substitution. The increased intensity of PhD-scientists in firms' R&D labor force stems from more researchers with PhD degrees compared to researchers without PhD degrees.

In models VI and VII displayed in table 3, the sample is split by firms in industries with lower employee turnover than the sample average and firms in industries with higher employee turnover. Results from the split sample regressions suggest that increasing R&D spendings on research equipment only impacts firm innovation in settings with high employee turnover. Though these results are preliminary and high-turnover sectors could be different from low-turnover sectors in other dimensions, it lends support to the theoretical idea that investment in research equipment may be an attractive strategy when it is difficult to retain human capital.

Table 3: **Mechanism: Retain and attract highly skilled human capital**

| | Model V: R&D workers w. PhD degree | | | Model VI: Sales from innovation | | | Model VII: Sales from innovation | | |
|---|---|---|---|---|---|---|---|---|---|
| *Sample* | | | | Low employee turnover industry | | | High employee turnover industry | | |
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Research equipment* | | | | | | | | | |
| Share R&D equipment | 0.284 | 0.002 | 0.094 | -1.474 | 0.549 | 2.457 | 6.616 | 0.009 | 2.524 |
| Share R&D equipment sq. | -0.394 | 0.003 | 0.133 | 1.233 | 0.776 | 4.329 | -10.074 | 0.013 | 4.029 |
| Controls | Yes | | | Yes | | | Yes | | |
| Sales growth/investment intensity | Yes | | | Yes | | | Yes | | |
| Industry fixed effects | Yes | | | Yes | | | Yes | | |
| Year fixed effects | Yes | | | Yes | | | Yes | | |
| Firm fixed effects | No | | | Yes | | | Yes | | |
| Number of observations/firms | 6,974/2,167 | | | 3,278/826 | | | 2,551/844 | | |
| Pseudo/Adjusted $R^2$ | 0.639 | | | 0.388 | | | 0.372 | | |

Robust standard errors clustered by firm. Sample restricted to firms with 10 or more employees for years 2007-2016. Model VI is a Tobit estimation due to the doubled cencored dependent variable: share of R&D workers with PhD degree. Models V and VI are estimated by ordinary least squares with firm fixed effects. In models V and VI, the sample is split by firms in industries with employee turnover above and below sample average turnover.

Table 4: **Heterogeneity: Laggards vs. leaders and small vs. large firms**

| | Model VIII: Sales from innovation | | | Model IX: Sales from innovation | | | Model X: Sales from innovation | | | Model XI: Sales from innovation | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Sample* | Industry laggard | | | Industry leader | | | Smaller Firm | | | Larger Firm | | |
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Research equipment* | | | | | | | | | | | | |
| Share R&D equipment | 4.270 | 0.019 | 1.825 | -0.640 | 0.512 | 0.975 | 4.227 | 0.022 | 1.847 | 1.538 | 0.621 | 3.106 |
| Share R&D equipment sq. | -8.505 | 0.001 | 2.649 | 2.710 | 0.343 | 2.843 | -8.237 | 0.004 | 2.892 | -0.942 | 0.863 | 5.464 |
| Controls | Yes | | | Yes | | | Yes | | | Yes | | |
| Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | |
| Industry fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Firm fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Number of observations/firms | 4,123/1,059 | | | 1,768/555 | | | 4,874/1,181 | | | 1,611/272 | | |
| Adjusted $R^2$ | 0.474 | | | 0.910 | | | 0.343 | | | 0.368 | | |

Robust standard errors clustered by firm. Sample restricted to firms with 10 or more employees for years 2007-2016. All models estimated by ordinary least squares with firm fixed effects. Innovation is measured as total sales from innovation. In models VII and VIII the sample is split by firms with sales from innovation above and below industry average. In models IX and X, the sample is split by large firms (> 250 employees as per OECDs defintion) and smaller firms.

In table 4 we further explore the idea that procuring research equipment may be a strategy to attract highly skilled huma capital. Splitting the sample first by firms who are industry laggards and leaders in terms of innovation output and by larger (more than 250 employees as per OECDs definition) and smaller firms, results from models VIII, IX, X, and XI show that increasing the share of spending on equipment only seem to matter for firms who are industry laggards as well as for smaller firms. These boundary conditions may be driven by diminishing returns to adding more research equipment for large and industry leading firms who may already have a high accumulated stock of research equipment. However, it may also imply that investing in research equipment is a strategy for firms who are not at the frontier and, thus, less prestigious to potential employees in order to attract them with the prospect of accessing cutting edge research equipment.

### 2.5.3 Robustness Checks

We perform a series of robustness checks of which the main ones are displayed in the appendix. In Table A.2, main estimations are rerun in ordinary least squares model without firm fixed effects The results of these models are consistent with main estimations though of higher magnitude, thus underscoring the importance of including firm fixed effects as results are to some extent driven by unobserved time-invariant factors possibly related to the underlying firm quality. Table A.2 also displays main models estimated as Tobit models with share of sales from innovation as the dependent variable instead of absolute sales. Results from these models are consistent with main findings.

In Table A.3, an additional set of controls are included addressing concerns that past innovation input and output drive results. These controls are three-year averages of innovation sales and R&D collaboration breadth along with dummies for whether the firm applied for or bought patents in the past three years leading up to the equipment spending. The aim of this exercise is to alleviate the endogeneity concern that the decision to invest in research equipment correlates with other innovation enhancing factors. It also serves to decrease concerns that firms who are already more innovative invest more in equipment. Our results are robust to the inclusion of these 3-year average controls of innovation input and output. The 3-year average controls are not included in main models as they reduce the size and generalizability of our sample.

Table A.4 displays the result of measuring research equipment as a three-year average as opposed to yearly spending accommodating that many firms do not invest in equipment every year. Model A-X shows that R&D equipment measured as a three-year average increases coefficient sizes as opposed to the original one-year variable. This may reflect that the three-year average more accurately captures firms' equipment investment levels. In Model A-XI and A-XII, the sample is restricted to firms with R&D spending on equipment and sales from innovation respective, both yielding consistent results.

## 2.6 Discussion

**Theoretical contributions** Drawing on human capital theory (Campbell et al., 2012; Coff, 1997) and insights from the economics of science literature (Dasgupta & David, 1994; Stephan, 1996, 2012), this study contributes to the innovation literature by conceptualizing physical capital and specifically research equipment as a significant input to the innovation production function. By theorizing and providing empirical evidence for the role of physical capital for human capital productivity as well as ability to attract and retain highly skilled human capital, this study opens up an interesting allay for the interplay between physical and human capital for firm innovation. The result that investing in research equipment is associated with more PhD-intensive research teams is interesting as previous research has found the inflow of academic scientist to positively influence firm innovation (Kaiser et al., 2018). Universities are faced with funding pressures which may open up an opportunity for firms to attract academic human capital with the prospect of working with cutting edge research equipment. The findings of this study calls for a more nuanced investigation of internal R&D spending and future research may further explore the role of spending on difference types of equipment under different conditions, and at certain timings.

**Managerial implications** For decision makers, the most striking insight from this study is the degree to which firms appear to underinvest in research equipment indicating that many firms may improve innovation performance by raising their equipment spending closer to optimum. Results from our heterogeneity analyses suggest that for smaller firms and firms who are not at the frontier, investing in new research equipment may be a strategic tool for attracting highly skilled human capital for R&D functions.

**Limitations** Our research has important limitations that shall be kept in mind. First, the choice to invest in research equipment is endogenous and as such our results shall be interpreted with caution. Moreover, we do not have detailed information about the types of equipment that is procured. There is presumably vast heterogeneity in the performance and quality of research equipment. Nonetheless, the representative dataset used for this study allows for valuable insights regarding the average effect of investments for the procurement of equipment and the general importance of such investments for innovative activities.

**Conclusion** This study analyses the impact of research equipment on firms' innovation performance. The empirical analysis based on a large representative sample of R&D active firms, suggests that firms can increase research productivity by procuring research equipment, especially for innovation of high novelty. This study contributes to the innovation literature by highlighting the role of research equipment for corporate R&D and by integrating insights from human capital theory and economic of science literature to theorize the interplay between human capital and physical capital for firm innovation.

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# Appendix B Supplementary Material

Table A.1: **Correlation table**

| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) | (19) | (20) | (21) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | Sales from innovation (thousand DKK) | 1.00 | | | | | | | | | | | | | | | | | | | | |
| (2) | Sales from innovation new to firm (DKK) | 0.82 | 1.00 | | | | | | | | | | | | | | | | | | | |
| (3) | Sales from innovation new to market (DKK) | 0.76 | 0.26 | 1.00 | | | | | | | | | | | | | | | | | | |
| (4) | Sales from innovation (share) | 0.22 | 0.14 | 0.21 | 1.00 | | | | | | | | | | | | | | | | | |
| (5) | Number of patents | 0.28 | 0.24 | 0.18 | 0.08 | 1.00 | | | | | | | | | | | | | | | | |
| (6) | Number of forward citations to patents | 0.24 | 0.22 | 0.12 | 0.06 | 0.84 | 1.00 | | | | | | | | | | | | | | | |
| (7) | Collaboration breadth | 0.18 | 0.12 | 0.16 | 0.24 | 0.16 | 0.10 | 1.00 | | | | | | | | | | | | | | |
| (8) | Equipment R&D spending (DKK) | 0.51 | 0.32 | 0.50 | 0.08 | 0.47 | 0.38 | 0.12 | 1.00 | | | | | | | | | | | | | |
| (9) | Physical capital (DKK) | 0.28 | 0.24 | 0.20 | 0.02 | 0.33 | 0.29 | 0.16 | 0.29 | 1.00 | | | | | | | | | | | | |
| (10) | Firm age | 0.08 | 0.06 | 0.07 | 0.01 | 0.09 | 0.06 | 0.10 | 0.09 | 0.06 | 1.00 | | | | | | | | | | | |
| (11) | Export (DKK) | 0.32 | 0.28 | 0.23 | 0.02 | 0.41 | 0.37 | 0.14 | 0.42 | 0.38 | 0.10 | 1.00 | | | | | | | | | | |
| (12) | Average hourly pay (DKK) | 0.04 | 0.02 | 0.05 | 0.03 | 0.04 | 0.03 | 0.05 | 0.09 | 0.07 | -0.07 | 0.03 | 1.00 | | | | | | | | | |
| (13) | Sales Growth | -0.00 | -0.00 | -0.00 | -0.01 | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 | -0.01 | -0.00 | -0.00 | 1.00 | | | | | | | | |
| (14) | Investments (DKK) | 0.31 | 0.24 | 0.26 | 0.02 | 0.37 | 0.28 | 0.15 | 0.43 | 0.57 | 0.07 | 0.55 | 0.05 | -0.00 | 1.00 | | | | | | | |
| (15) | R&D cost | 0.16 | 0.14 | 0.11 | 0.02 | 0.20 | 0.19 | 0.12 | 0.31 | 0.18 | 0.06 | 0.34 | 0.06 | -0.00 | 0.25 | 1.00 | | | | | | |
| (16) | Startup dummy | -0.02 | -0.02 | -0.02 | 0.03 | -0.02 | -0.01 | -0.00 | -0.01 | -0.02 | -0.24 | -0.03 | 0.03 | -0.00 | -0.03 | -0.01 | 1.00 | | | | | |
| (17) | Public dummy | -0.09 | -0.01 | 0.01 | -0.01 | 0.03 | 0.02 | 0.00 | 0.01 | -0.01 | 0.14 | -0.00 | 0.02 | 0.00 | 0.01 | 0.01 | -0.11 | 1.00 | | | | |
| (18) | Capital dummy | 0.02 | 0.01 | 0.02 | 0.03 | 0.05 | 0.05 | 0.04 | 0.04 | 0.06 | -0.07 | 0.00 | 0.35 | -0.00 | 0.05 | 0.04 | 0.05 | -0.06 | 1.00 | | | |
| (19) | Manufacturing | 0.05 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 | 0.07 | 0.01 | 0.00 | 0.29 | 0.09 | -0.39 | 0.00 | 0.02 | -0.00 | -0.13 | 0.19 | -0.42 | 1.00 | | |
| (20) | IT & Communications | -0.02 | -0.02 | -0.02 | 0.00 | -0.05 | -0.03 | -0.13 | -0.01 | 0.01 | -0.22 | -0.06 | 0.27 | -0.00 | 0.01 | -0.01 | 0.10 | -0.06 | 0.30 | -0.61 | 1.00 | |
| (21) | Technical services | -0.04 | -0.03 | -0.03 | -0.04 | 0.01 | 0.01 | 0.04 | 0.00 | -0.01 | -0.13 | -0.05 | 0.21 | -0.00 | -0.04 | 0.02 | 0.06 | -0.17 | 0.20 | -0.61 | -0.26 | 1.00 |

All pairwise correlations larger than 0.02 (in absolute terms) are significant at the 5% level

Table A.2: **Main effects estimated with OLS and Tobit**

| | Model A-I: Sales from innovation | | | Model A-II: Sales from innov. new to firm | | | Model A-III: Sales from innov. new to market | | | Model A-IV: Share sales from innovation | | | Model A-V: Share sales innov. new to firm | | | Model A-VI: Share sales innov. new to market | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Research equipment* | | | | | | | | | | | | | | | | | | |
| Share R&D equipment | 6.276 | 0.000 | 1.358 | 4.635 | 0.000 | 1.324 | 7.389 | 0.000 | 1.350 | 0.797 | 0.000 | 0.216 | 0.357 | 0.000 | 0.155 | 0.935 | 0.000 | 0.197 |
| Share R&D equipment sq. | -9.547 | 0.000 | 1.709 | -6.734 | 0.000 | 1.659 | -10.711 | 0.000 | 1.612 | -1.253 | 0.000 | 0.293 | -0.556 | 0.000 | 0.219 | -1.488 | 0.000 | 0.276 |
| Controls | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| Industry fixed effects | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| Year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | | Yes | | |
| Firm fixed effects | No | | | No | | | No | | | No | | | No | | | No | | |
| Number of observations/firms | 7705/2,587 | | | 7705/2,587 | | | 7705/2,587 | | | 7705/2,587 | | | 7705/2,587 | | | 7705/2,587 | | |
| Adjusted $R^2$ | 0.151 | | | 0.109 | | | 0.110 | | | 0.026 | | | 0.043 | | | 0.027 | | |

Robust standard errors clustered by firm. Sample restricted to firms with 10 or more employees for years 2007-2016. In models A-I - A-III innovation is measurd as total sales for innovation estimated by ordinary least squares. In models A-IV - A-VI innovation is measured as share of sales from innovation estimated by Tobit.

Table A.3: **Controls for past innovation inputs and outputs**

| | Model A-VII: Sales from innovation | | | Model A-VIII: Sales from innov. new to firm | | | Model A-IX: Sales from innov. new to market | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Research equipment* | | | | | | | | | |
| Share R&D equipment | 5.452 | 0.008 | 2.031 | 4.297 | 0.059 | 2.225 | 8.724 | 0.000 | 2.282 |
| Share R&D equipment sq. | -8.657 | 0.005 | 3.025 | -6.841 | 0.037 | 3.244 | -12.739 | 0.000 | 3.462 |
| *Additional controls: 3-year average* | | | | | | | | | |
| Log innovation sales | 0.391 | | 0.027 | 0.217 | | 0.026 | 0.297 | | 0.026 |
| Applied for patents | 0.721 | | 0.251 | -0.162 | | 0.285 | 1.163 | | 0.280 |
| Bought patents | 0.392 | | 0.223 | 0.528 | | 0.266 | 0.286 | | 0.262 |
| Collaboration breadth | 0.265 | | 0.059 | 0.235 | | 0.069 | 0.270 | | 0.069 |
| Controls | Yes | | | Yes | | | Yes | | |
| Sales growth/investment intensity | Yes | | | Yes | | | Yes | | |
| Industry fixed effects | Yes | | | Yes | | | Yes | | |
| Year fixed effects | Yes | | | Yes | | | Yes | | |
| Firm fixed effects | No | | | No | | | No | | |
| Number of observations/firms | 3,212/1,052 | | | 3,211/1,052 | | | 3,211/1,052 | | |
| Adjusted $R^2$ | 0.300 | | | 0.189 | | | 0.228 | | |

Robust standard errors clustered by firm. Sample restricted to firms with 10 or more employees for years 2007-2016. All models estimated by ordinary least squares. Innovation is measured as total sales from innovation.

Table A.4: **Alternative dependent variable and sample cuts**

| *Indepdendent variable/Sample* | Model A-X: Sales from innovation | | | Model A-XI: Sales from innovation | | | Model A-XII: Sales from innovation | | |
|---|---|---|---|---|---|---|---|---|---|
| | Research equipment averaged 3-yrs. | | | Research equipment within sample | | | Innovation sales within sample | | |
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Research equipment* | | | | | | | | | |
| Share R&D equipment | 8.058 | 0.037 | 3.853 | 3.284 | 0.036 | 1.566 | 3.461 | 0.039 | 1.672 |
| Share R&D equipment sq. | -14.062 | 0.155 | 9.870 | -5.571 | 0.036 | 2.649 | -6.069 | 0.038 | 2.921 |
| Controls | Yes | | | Yes | | | Yes | | |
| Sales growth/investment intensity | Yes | | | Yes | | | Yes | | |
| Industry fixed effects | Yes | | | Yes | | | Yes | | |
| Year fixed effects | Yes | | | Yes | | | Yes | | |
| Firm fixed effects | Yes | | | Yes | | | Yes | | |
| Number of observations/firms | 3.410/711 | | | 4.579/856 | | | 6,056/1,268 | | |
| Adjusted $R^2$ | 0.461 | | | 0.376 | | | 0.298 | | |

Robust standard errors clustered by firm. Sample restricted to firms with 10 or more employees for years 2007-2016. All models estimated by ordinary least squares. Innovation is measured as total sales from innovation.

# Chapter 3: **The Non-linear Relationship between Horizontal Pay Dispersion and Technological Knowledge Production**

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## 3.1 Introduction

With roots in the knowledge-based view of the firm (Grant, 1996), it is widely acknowledged that firm innovation to a large extent is determined by the knowledge embedded in organizations' human capital as well as the knowledge sharing among individuals to create new combinations of knowledge (Kogut and Zander, 1992; Tsai, 2001; Grigoriou and Rothaermel, 2014; Haas and Ham, 2015). Consequently, research within the innovation literature looks at firms' human capital, e.g., labor composition and mobility of knowledge workers (e.g., Song, Almeida and Wu, 2003; Singh and Agrawal, 2011; Kaiser et al., 2018) and its effect on invention outcomes. While human capital determines the pool of knowledge available to the firm, organizational structure and practices affects how this pool of knowledge may be utilized through collaboration and motivation mechanisms (Garicano, 2000; Manso, 2011; Patacconi, 2009).

Complementing human capital literature are studies looking at how organizational structure and practices shape decisions and outcomes for R&D and innovation (e.g., Brown and Duguid, 1991; Argyres and Silverman, 2004; Foss, Laursen and Pedersen, 2011). Pay structure is a key organizational practice which is closely linked to organization structure and has been shown to affect multiple organizational outcomes including employee turnover (John Michel, 2002a; Carnahan, Agarwal and Campbell, 2012; Kacperczyk and Balachandran, 2018), firm performance (Brown, Sturman and Simmering, 1996; Bloom and Milkovich, 1998; Bloom, 1999; Lazear, 2000a), and invention (Balkin, Markman and Gomez-Mejia, 2000; Lerner and Wulf, 2007a; Ederer and Manso, 2013; Yanadori and Cui, 2013; Cui, Ding and Yanadori, 2019). Building on social comparison theory and compensation theory, Yanadori and Cui (2013) predict and find a negative relationship between horizontal pay dispersion among R&D employees and patents.

While high pay differentials may be conductive to individual performance through motivation mechanisms, it may be detrimental to collaborative behavior and thereby team performance. High pay differentials may incentivize individuals to prioritize their own performance at the expense of team performance to win the tournament price, i.e., the higher salary (Bloom, 1999; Gerhart & Rynes, 2003). High pay dispersion, especially among employees at the same hierarchical level, that is horizontal pay dispersion, may install feelings of unfairness and distrust due to social comparison which further hinders collaboration (Fredrickson, Davis-Blake and Sanders, 2010). As innovation is a collaborative process relying on knowledge distributed across individuals, the negative consequences of pay dispersion have been argued and shown to outweigh the positive.

Following the method by Kacperczyk & Balachandran (2018), I use International Standard Classification of Occupations (ISCO) to create hierarchical layers within the firm to calculate to horizontal and vertical pay dispersion measured as the Gini coefficient. I rely on data from the European Patent Office (EPO) to measure technological knowledge production. These datasets are linked to the Integrated Database for Labor Market Research (IDA) from Statistics Denmark to obtain individual wages among other information at the individual and firm level. And to identify R&D workers through information on educational background and functional position in the focal firm.

I set out by replicating the finding by Yanadori & Cui (2013) that pay dispersion at the horizontal level, i.e., pay differentials between R&D workers at the same organizational layer is negatively related to new patent filings. Though negative at a first glance, the relationship becomes weekly positive when considering firm-fixed effects. Including a squared term of horizontal pay dispersion, I find a non-linear inverted u-shaped relationship between pay dispersion and knowledge production. Plotting marginal effects reveals that the majority of firms in my sample has pay dispersion below the infliction point at which dispersion becomes detrimental to knowledge production. These results seem to suggest that while the negative effects of pay dispersion on the collaborative nature of knowledge creation holds at a certain level of dispersion, the positive effect of pay inequality appears to outweigh the negative ones at lower levels of dispersion. Hence, by extending the model of Yanadori & Cui (2013), I provide evidence that the optimal structure for innovation may not be as egalitarian as we have traditionally thought (Burns & Stalker, 1994).

I explore the theoretical mechanism of social comparison (Fredrickson et al., 2010) by showing that pay dispersion only seem to impact knowledge production in firms with single R&D establishments as opposed to multiple establishments, indicating that social comparison is a driver when employees can compare themselves and their salaries with colleagues at the same physical location. I also show another interesting boundary condition in that pay dispersion only appear to affect knowledge production when the focal firm is surrounded by a local dynamic labor market with a large presence of R&D intensive firms. Employees may not only compare themselves with co-workers at the same geographical location but also with workers in other firms within the same geographical region. In other terms, social comparison mechanisms seem to span boundaries of the organization.

This paper makes two main contributions to extant literature. First, by providing evidence that past findings of a negative relationship between horizontal pay dispersion and knowledge production may be driven by unobserved time-invariant firm qualities, as the negative effect disappears by the inclusion of firm fixed effects. In firm-fixed models, I show that pay dispersion and knowledge production follows a non-linear u-shaped association. Finding that the relationship between pay dispersion and performance is non-linear has important theoretical and managerial implication when it comes to the mechanisms of pay structure. Second, I identify boundary conditions which suggests that social comparison is the driving mechanisms behind the impact of horizontal pay dispersion on knowledge production. Although preliminary, these results may suggest that the effect of pay structure is not only dependent on internal firm conditions but that the external labor market has to be taken into account by decisions makers designing pay structures in firms.

## 3.2 Theory

Innovation is a complex process relying on the generation of new knowledge and, thus, highly skilled human capital is especially important (Haas & Ham, 2015; Kogut & Zander, 1992). Pay is an important tool in attracting and retaining highly qualified human capital (Andersson et al., 2009; Kacperczyk & Balachandran, 2018). In addition to having an effect on individuals' decision to join or leave the firm, and more importantly for this study, pay also affects individuals' efforts and propensity to collaborate or compete with colleagues while working in the firm (Bloom, 1999). Pay dispersion refers to pay inequality and can be distinguished by a vertical and a horizontal dimension. Vertical pay dispersion refers to wage inequality between organizational layers (Devaro, 2006). A high vertical pay dispersion corresponds to a classic hierarchical organization where pay increases as employee moves up the hierarchical ladders. Horizontal pay dispersion refers to pay inequality within organization layers, hence between employees occupying similar ranks in the firm (Gupta et al., 2012; Siegel & Hambrick, 2005).

### 3.2.1 Pay Dispersion and Performance

The arguments in favor of high pay dispersion when it comes to performance are tied to individuals' motivation. As such, pay can be viewed in terms of agency theory as a principal-agent problem (Alchian & Demsetz, 1972; Bloom & Milkovich, 1998; Foss & Laursen, 2005). The principal (manager) seeks to maximize agent (employee) effort, while the agent is assumed to minimize effort creating a relationship of divergent interests. By the lack of constant monitoring, setting up a pay structure that incentivizes performance, may provide a solution to the problem of divergent interests, in which agents maximize effort incentivized by maximizing income. Hence, in a setting where individual performance is traceable, a high pay dispersion driven by performance differences should increase performance. Along the same lines, pay is a means to reward employee effort (Gerhart & Rynes, 2003) and can motivate employees to improve their performance (Vroom, 1964). Vertical dispersion, that is consecutively increasing pay by hierarchical layer, may be especially well suited to induce employee motivation and effort as individuals exert more effort in the expectation of future reward (Vroom, 1964), by the expectation of moving up the organization hierarchy to receive higher pay.

High pay variation also increases firms' ability to attract highly qualified human capital such as star scientists as well as retaining the high performers in the firm (Andersson et al., 2009; Kacperczyk & Balachandran, 2018; Lazear, 2000b). However, the sorting argument is less likely to drive performance effects from pay dispersion in my setting as this will increase the pay level of the firm and thereby be controlled out of the analysis both in the construction of the pay dispersion variables and as a control in regression models.

Horizontal pay dispersion, i.e., variation among individuals at the same hierarchical layer, is a means to set up a market-like structure at the workplace where highest performing employees receive larger compensation such that individual effort is rewarded regardless of prospects of moving up the hierarchy (Nickerson & Zenger, 2008). This incentive system may increase competition through social comparison and increase employee efforts (Trevor et al., 2012). But it relies on the ability to measure performance indicators to which the pay is tied. Linking pay to performance motivates employees to increase their performance (Vroom, 1964), but it may have the opposite effect if the pay distribution is perceived as unfair by employees in which case, they may withhold effort (Levine et al., 1993). This is especially true for horizontal dispersion as individuals may perceive pay differential to individuals who are similar to themselves, e.g., at the same rank, as unfair, such that social comparison becomes negative for performance (Fredrickson et al., 2010).

### 3.2.2 Pay Dispersion and Knowledge Production

Arguments in favor of pay dispersion and performance are tied to individual performance. While individuals' knowledge and entrepreneurial drive play a key role for innovation, creating new knowledge is a collaborative process relying on the shared contributions of multiple individuals (Haas & Ham, 2015; Kogut & Zander, 1992). For this reason, a pay structure that favors collaboration would be the preferred structure for innovation. High pay dispersion may lead individuals to prioritize individual performance over the performance of the team, by for example withholding knowledge to keep a relative advantage over colleagues whom they see as competitors (Pfeffer & Langton, 1993). This is especially detrimental to innovation for which knowledge sharing is an essential component. High pay differentials may evoke feelings of distrust and divide which further hampers collaboration (Levine et al., 1993). These negative effects are expected to be especially present at the horizontal level where they are aggravated by social comparison mechanisms (Fredrickson et al., 2010).

Turning again to agency theory, in addition to being effort-minimizing agents are risk-minimizing (Bloom & Milkovich, 1998; Foss & Laursen, 2005). Innovation activities are inherently risky behavior with a substantial component of exploration of different combinations many of which many fail (Ederer & Manso, 2013). Hence, tying individual pay variation to performance indicators may motivate R&D workers to pursue ideas of lower novelty as these entail less risk (Cui et al., 2019). Uncertainty in innovation outcome also increase errors in performance measures (Holmstrom, 1989; Prendergast, 2002), which is likely to promote feelings of unfairness and dissatisfaction among employees (Gupta et al., 2012; Levine et al., 1993; Pfeffer & Langton, 1993).

These arguments against pay dispersion, especially on the horizontal axis, explains previous negative predictions and findings on pay dispersion and team performance (Bloom, 1999;

Yanadori & Cui, 2013). However, most of these arguments are tied to pay dispersion driven by pay for performance. In a call center it is easy to imagine the measurement of performance indicators such as number of phone calls handled, number of customer complaints resolved, or sales numbers. In this setting and other settings where key performance indicators (KPIs) can be traced at a reasonable cost (Lazear, 2000a), pay for performance is expected to be prevalent following the arguments from expectancy theory (Vroom, 1964) and agency theory (Alchian & Demsetz, 1972). However, when it comes to R&D teams and the creation of knowledge, it is much measure performance due to learning and experimentation (Ederer & Manso, 2013). Therefore, I argue, that pay for performance is unlikely to drive pay dispersion among R&D workers.

Instead, pay dispersion among R&D workers may be based in pay differentials linked to a set of observable quality signals at the individual level. R&D workers, namely researchers, differ from the general population of workers in that their relative human capital can be accessed through a number of observables such as the rank of the institution from which they have their degree, patents and awards, and functional specialization. Pay differentials on the basis of these quality indicators may increase effort and motivation by the individuals receiving the pay, because their specific qualities are rewarded (Gerhart & Rynes, 2003). On the other hand, such pay differentials may not have negative effects due to social comparison mechanisms on the motivation of R&D workers receiving a lower compensation, as these pay differentials may be perceived as fair (Levine et al., 1993). Furthermore, researchers may be intrinsically motivated (Amabile, 1997) by the research task itself such that agency-theory predictions on effort-minimization may not be prevalent in the setting of R&D workers.

Assuming that pay dispersion among R&D employees are driven by pay differentials based on individuals' qualities rather than pay for performance, the negative externality of pay dispersion pertains to feelings of divide and inequality which hinders knowledge sharing and collaboration (Pfeffer & Langton, 1993). Such negative effects may only kick in at relatively high levels of pay dispersion such that the positive motivational effects of rewarding individual quality are not outweighed by the negative effects of inequality at lower levels of pay dispersion.

Few empirical studies have been done on the relationship between pay dispersion and knowledge production, most of which consider pay dispersion at the executive level (Amore & Failla, 2020; Balkin et al., 2000; Dechow & Sloan R G, 1991; Holthausen et al., 1995; Lerner & Wulf, 2007). These studies find incentives with a long-time horizon, such as stock options, are beneficial to firm innovation. Executives influence corporate R&D and innovation by directing resources and managerial attention. R&D employees, on the other hand, are at the center of knowledge creation making motivation and collaboration mechanisms driven by pay dispersion more directly linked to innovation. Cui, Ding and Yanadori (2019) show that vertical pay dispersion in the R&D workforce is associated with more exploratory patents while horizontal pay dispersion is negatively associated with exploration. Most closely related to my study, Yanadori and Cui (2013) find a negative correlation between horizontal pay dispersion of R&D workers and number of patents. To the best of my knowledge, my study is the first to theorizing and empirically exploring potential non-linearities.

Following the approach by Yanadori and Cui (2013) I focus on horizontal pay dispersion rather than vertical pay dispersion although I control for the vertical dimension. Vertical pay dispersion, i.e., pay inequality between organizational layers is unlikely to drive performance of R&D teams. When it comes to R&D employees, their position within the firm hierarchy is relatively stable. If you are a lab technician, you are unlikely to move to a higher layer by a promotion to researcher as these functions require different educational backgrounds. Furthermore, R&D employees when compared to for example business professionals, may prefer to stay in their specialist roles as opposed to climbing the organizational hierarchy to reach supervisor or managerial positions which are of a more general nature. R&D workers are, thus, unlikely to be motivated by tournament incentives.

## 3.3 Data

### 3.3.1 Empirical Setting

I investigate the relationship between horizontal pay dispersion and knowledge production in the empirical setting of Denmark. This setting is attractive as Danish employers report salaries of employees to a central tax authority implying that individual salaries, and thus, pay structure can be measured accurately. Furthermore, employer-employee linked labor market data allows me to track employees' educational backgrounds as well as functional and hierarchical position in the focal firm providing unique benefits for investigating the relationship between pay dispersion and knowledge production. Datasets used in this paper covers the universe of Danish firms such that a large sample can be obtained even with the sample restriction that firms need to be R&D intensive. A large and balanced panel enables the inclusion of firm fixed effects which are relative demanding on the statistical power of models. As results will demonstration, controlling for time-invariant firm qualities is important in identifying the association between pay and patents.

In Denmark, wages are to a large extent determined by collective bargains between labor unions and employers implying that employees in the same job functions and seniority ranks have similar base salaries. Hence, variation in pay tends to come from bonused based on qualifications and performance. This also implies that dispersion to a large extent is driven by variation in the higher end of the pay distribution as opposed to the lower end. Potential negative effects of increased pay dispersion are, thus, unlikely to arise because of variation in the lower end of the pay distribution where individuals withhold effort due pay below their hygiene wage.

### 3.3.2 Linked Employer-Employee Data and Patent Data

The Integrated Database for Labor Market Research (IDA) provided by the national statistics bureau, Statistics Denmark, is used to identify individual salaries as well as hierarchical layers inside the firm based on individual occupational codes. I link this dataset to a general firm register to obtain firm-level information including corporation type, firm age, and financial data. A key feature of this dataset is the ability to track linked employer-employee data over time and it has been used in numerous studies published in top journals (for instance, Dahl & Sorenson, 2012; Kaiser et al., 2018; Rocha & van Praag, 2020). Firms can be reliably followed over time from year 1999 and onwards. Patent data from the European Patent Office (EPO) is matched to the IDA data to obtain firm-level measures of new patent applications which I have available until 2012.

### 3.3.3 Dependent Variables

To measure the relationship between pay dispersion and firms' ability to produce technological knowledge I employ a classic measure of technological knowledge reflected by the *number of new patents* in a given year (Trajtenberg, 1990). Patents are measured as number of patent application filings recorded at the priority date, that is, the first date of filing the application. The advantage of using the priority date as registration of a new patents is that this is the first formal record of new knowledge.

### 3.3.4 Independent Variables

My main independent variable is horizontal pay dispersion. Following the same approach as Kacperczyk & Balachandran (2018), I use International Standard Classification of Occupations (ISCO) to establish layers within the firm hierarchy and measure pay dispersion within and between theses layers using the Gini Coefficient. This method of constructing the firm hierarchy has been used in multiple studies (Caliendo et al., 2015; Tåg, 2013; Tåg et al., 2016) and creates four layers inside the firm: 1) Management, 2) High knowledge professionals, 3) Medium knowledge professionals, and 4) Basic knowledge professionals. Table 1 illustrates that this approach establishes a classic hierarchy where the number of employees decrease and pay levels increase by rank.

Table 1: **Layers in the firm hiearchy**

| Mean | No. of Employees | Pay average (Hourly DKK) |
|---|---|---|
| **1. Management** | | |
| Senior officials and managers | 48.583 | 445.472 |
| **2. High knowledge professionals** | | |
| E.g. engineers, researchers, business analysts | 462.481 | 269.729 |
| **3. Medium knowledge professional** | | |
| E.g. technicians, corporate salesmen | 386.500 | 224.833 |
| **4. Basic knowledge workers** | | |
| E.g. clerks, mashine operators, office secretaries | 761.067 | 182.968 |

Based on International Standard Classification of Occupations (ISCO)

I restrict my calculation of the Gini coefficient to include only layers; 2) High knowledge professionals and 3) Medium knowledge professionals. Basic knowledge professionals include job functions such as machine operators and cashiers and are assumed not to have any noticeable impact on knowledge creation. The managerial layer is excluded from the Gini coefficient calculation as my theoretical reasoning is built around the relationship between pay differentials among R&D workers and production of knowledge. Incentives at the managerial layer are fundamentally different from those at the worker layers such that theories of future reward and collaboration does not apply to the same extent.

Gini coefficients are calculated for R&D workers within the firm. *R&D workers* are defined as individuals with a higher degree (Bachelor's, Master's, or PhD) in a STEM related field (technical, natural, veterinary, agricultural, and health sciences) occupying high and medium knowledge positions (Kaiser et al., 2015). High knowledge professionals (layer 2) corresponds to researchers, while medium knowledge professionals (layer 3) corresponds to technicians. Individuals' education backgrounds are identified by linking my dataset to a register containing information on highest completed education. Position within the firm hierarchy is determined via International Standards Classification of Occupations codes at the 1-digit level.

Figure 1 illustrates labor composition of the R&D workforce for firms in my sample, while Figure 2 shows the labor composition of all employees having their main occupation with the firm. As one would expect, when considering all employees in the firm, the largest layer is the basic layer while number of employees decease as the rank increases. For R&D employees however, the high knowledge layer is by far the largest indicating the R&D workforce of these R&D intensive firms consist mainly of researchers.

Figure 1: R&D labor composition

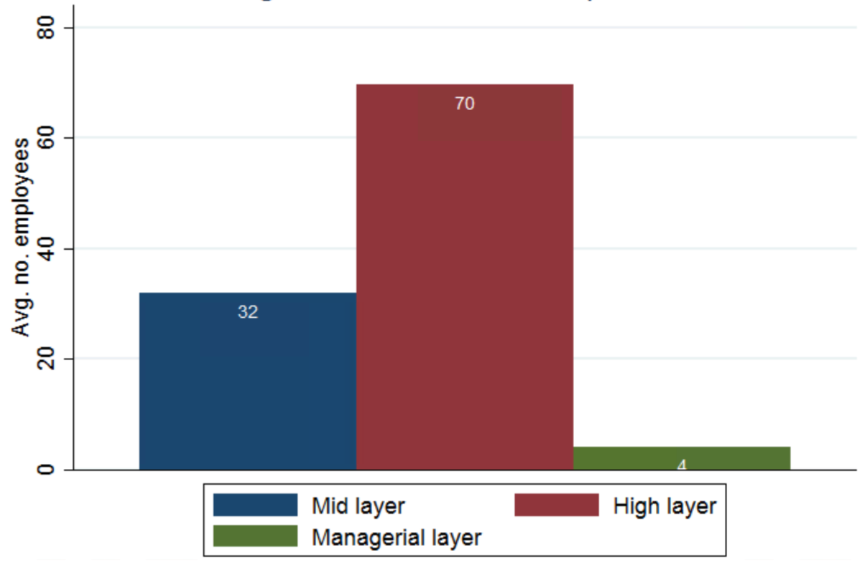
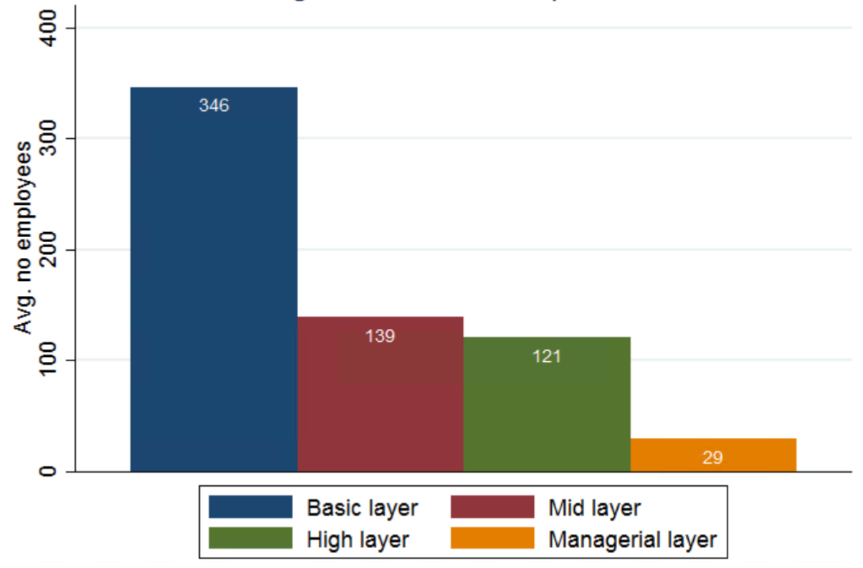



Figure 2: Labor composition



Following previous research on pay dispersion (e.g., Bloom, 1999; John Michel, 2002b; Sørensen and Sharkey, 2014; Kacperczyk and Balachandran, 2018), I measure pay dispersion by the Gini coefficient which is given by the following formular:

$$Gini = \frac{2\sum_{i=1}^{m} iw_i}{m\sum_{i=1}^{m} w_i} - \frac{m+1}{m} \tag{1}$$

$w_i$ denotes hourly salary of an individual at the $i$th layer in the organizational hierarchy indexed in nondecreasing order and $m$ denotes count of workers at a given layer. A Gini coefficient of 0 reflects a situation of total equality where all employees at the layer earns the same while 1 reflects absolute dispersion. After calculating dispersion at each layer, I add them up and divide by the number of layers to obtain the measure of *horizontal pay dispersion.* For the analysis, I include only two layers and restrict my sample to firms with employees in both layers implying that number of layers is always two.

Similar to the approach for the horizontal Gini, the vertical Gini is calculated using average pay within a layer as inputs to formular (1) instead of individual salaries such that $w_i$ equals the average of salaries within a given layer and $m$ is the number of layers. Again, the number of layers is always two due to my theoretical focus on R&D workers which are found at two layers within the firm hierarchy. This also means, that the vertical Gini by construction ranges between 0 and 0.5. Using salary averages by group as an input to the Gini coefficient to calculate vertical dispersion is an approach the has been used by several scholars (e.g., Ohtake, 2008; Cowell, 2011; Kacperczyk and Balachandran, 2018) To alleviate concerns of reverse causality, all independent variables including controls are lagged by one year.

### 3.3.5 Control Variables

I control for a set of factors at the firm-level and worker group-level which may affect patent outcomes. I control for logged *Number of R&D workers* as R&D workers are likely to affect dispersion and patents. A control for *Pay average* is included as horizontal Gini increases with pay level as seen in Figure 4. Furthermore, increased pay levels are likely to increase knowledge production due to the increased ability to attract and retain highly skilled human capital. I control for *average* and *standard deviation* of worker *age* and *tenure* within the firm to capture the level and variation in both tenure on the job market (proxied by worker age) and seniority within in the firm (proxied by tenure) as these are important drivers of pay levels. *Vertical pay dispersion* is included as a control.

I include a host of firm characteristics which may affect firms' ability to produce knowledge. Controls include *firm size* as measured by number of employees (including only those having their main occupation with the firm), *firm age* measured as years since the firm was established, *physical capital* given by the natural logarithm of the book value of firms' fixed assets. The *number of establishments* reflecting the total number of physical working places within the firm is included as a control as physical dispersion of workers may affect both pay dispersion and collaboration mechanisms. I include two dummies controlling for whether the firm is a *publicly traded* company and located in the *capital region* which in this setting is the greater area of Copenhagen. As a measure of investment opportunities and actual investments I control for *sales growth* and the logged value of *net investments*. All models control for year, industry, and firm fixed effects. In robustness checks I include a control for R&D spending as this is an important determinant of innovation potential. This variables comes from the Community Innovation Survey which is a sample as opposed to the full population of firms available in other datasets used for this study. Hence, to preserve a large-unbalanced sample, R&D intensity is not included in main specifications.

### 3.3.6 Sample

While The Integrated Database for Labor Market Research (IDA) database includes the universe of firms in Denmark (~ 300,000 active firms excl. holding companies but including solo ventures which account for half of the firms) uniquely identified from 1999 and until now, my analysis sample is restricted to the availability of patent data until and including 2012. I restrict my sample to firms with at least six R&D employees at each relevant layer (layer 2 and 3). This leaves me with a sample of 4,151 observations and 838 unique firms for years 2002-2012. I restrict the sample to firms with multiple employees at each firm layer to ensure meaningful variation in the dependent variable. For robustness, different layer size cutoffs are used. This restriction also implies that the sample is representative relatively large and R&D intensive firms compared to the Danish population of firms, but smaller than the average firm size of samples typically used for studies on pay dispersion as these are often American studies for which detailed pay information is only available for a subset of corporations which are typically very large

### 3.3.7 Descriptive Statistics

Table 2 to shows descriptive statistics for main variables reported for the sampled firms. An average firm in my sample files 1.264 new patent applications per year reflecting the fact that few firms file for new patents regularly. Turning to the measure of horizontal pay dispersion, which is my main explanatory variable, average horizontal Gini coefficient of R&D employees is 0.125 which is slightly lower than comparable variables in related research. Yanadori & Cui (2013) report a horizontal dispersion of 0.177 and Cui et al (2019) report 0.181 for the same variable both in the setting of large American firms. Figure 3 illustrates that horizontal pay dispersion increases with firm size (small < 50, medium <= 250, large > 250 as per OECDs definition) and figure 4 shows that horizontal pay dispersion increases with pay level of the firm such that firms in the upper quartile of the pay distribution have higher pay variation among employees at the same rank as compared to firms at lower quartiles. Interestingly, firms in low-tech industries (OECD definition based on R&D intensity) have higher pay dispersion than firms in medium- and high-tech industries.

Figure 3: Pay dispersion by firm size

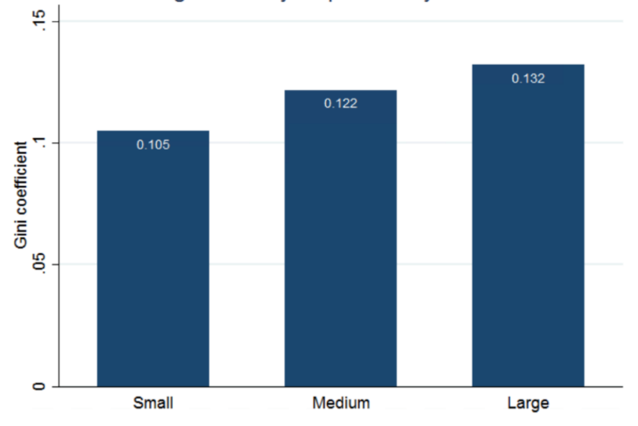



Figure 4: Gini by pay level

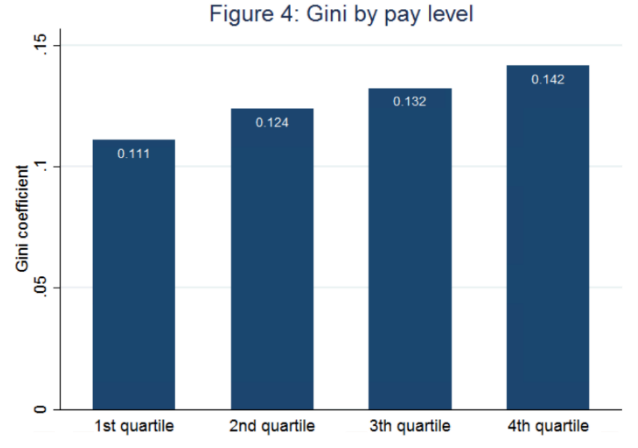



Figure 5: Gini by industry

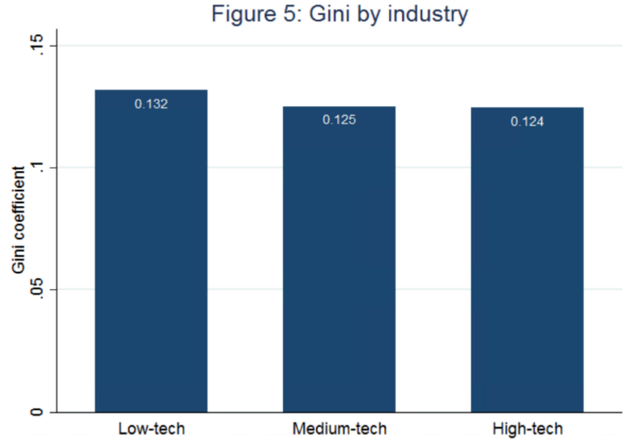


Table 2: **Descriptive statistics for main variables**

| | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| *Technological knowledge* | | | | |
| Number of patents | 1.264 | 6.659 | 0 | > 130 |
| *Pay dispersion* | 0.125 | 0.036 | 0 | 0.427 |
| Horizontal gini - R&D workers | | | | |
| *Controls: R&D workers* | | | | |
| Vertical gini | 0.049 | 0.035 | 0 | 0.254 |
| Number of R&D workers | 151.804 | 428.127 | 10 | > 8,000 |
| Pay average (Hourly DKK) | 264.688 | 46.978 | 68.5 | 796.690 |
| Tenure standard deviation | 4.748 | 2.293 | 0 | 14.590 |
| Tenure average | 4.855 | 2.589 | 0 | 17.389 |
| Age standard deviation | 9.340 | 1.631 | 2.112 | 16.032 |
| Age average | 41.858 | 3.919 | 25.549 | 57.667 |
| *Controls: Firm* | | | | |
| Firm size | 1,838.548 | 6,360.36 | 16 | > 180,000 |
| Firm age | 26.039 | 22.034 | 0 | > 200 |
| Physical capital (thousand DKK) | 1,420,076 | 4,718,249 | 0 | >119,000,000 |
| No. of establishmetns | 31.153 | 82.609 | 1 | > 1,000 |
| Capital region dummy | 0.462 | 0.499 | 0 | 1 |
| Public dummy | 0.686 | 0.464 | 0 | 1 |
| Investment intensity | 0.063 | 0.132 | 0 | 1 |
| Sales growth | 16.870 | 1250.854 | -1 | > 300 |

The average firm in my sample has 152 R&D workers. R&D workers have, on average, 5 years of experience in the focal firm and an average age of 42. The relative high age may be driven by the high education level of these workers such that they enter le labor market in their thirties. The average firm is 26 years old. 69 percent of firms are publicly traded companies and 46 percent are located in the greater capital region. The average number of establishments within a firm is 31 different physical locations.

## 3.4 Results

I regress patents on a Gini coefficient reflecting horizontal dispersion along with the rich set of control variables. Poisson models which are the natural choice for over dispersed count data with many zeros are used as the dependent variable is patent counts. In addition to Poisson estimations, separate models are estimated by ordinary least squares to allow for the inclusion of firm fixed effects In these model the dependent variable is logged due to its skewed distribution. Given the panel structure of the data and, thus, repeated observations of firms, standard errors are clustered at the firm level in all models. All independent variables are lagged by one year.

### 3.4.1 Main Results

Table 3 reports the estimated effects of pay dispersion among R&D workers on number of patents as a measure of technological knowledge output or invention. In line with the expectation based on previous research, results in model shows that horizontal pay dispersion is statistically significant and negatively associated with output implying that increased pay inequality among R&D workers appears to be negative for knowledge production. Interestingly, as displayed in model II, the results is positive and significant when the relationship between dispersion and patents is estimated in a linear model with firms fixed effects. Including a squared term of horizontal pay dispersion both the Poisson estimation (model III) and OLS estimation (model IV) shown a non-linear relationship with the original term as positive and the squared term as negative.

Results from table 3 indicates that a certain level of pay differentials among R&D employees is beneficial to reward differences in skills and efforts and that the detrimental effects on collaboration from feelings of inequality and competition only kicks in at higher levels of dispersion.

Table 3: **The effect of horizontal pay dispersion on firms' technological knowledge**

| | Model I: Poisson | | | Model II: OLS | | | Model III: Poisson | | | Model IV: OLS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of patents | | | Number of patents | | | Number of patents | | | Number of patents | | |
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Pay dispersion* | | | | | | | | | | | | |
| Horizontal gini | -4.924 | 0.048 | 2.491 | 0.604 | 0.023 | 0.266 | 49.122 | 0.008 | 18.553 | 2.049 | 0.016 | 0.847 |
| Horizontal gini squared | | | | | | | -191.632 | 0.003 | 64.274 | -4.813 | 0.049 | 2.439 |
| *Controls: R&D workers* | | | | | | | | | | | | |
| Vertical gini | 3.506 | 0.137 | 2.356 | -0.024 | 0.948 | 0.377 | 4.010 | 0.088 | 2.347 | 0.047 | 0.900 | 0.379 |
| Log R&D workers | 0.590 | 0.001 | 0.174 | 0.094 | 0.083 | 0.054 | 0.523 | 0.002 | 0.171 | 0.092 | 0.090 | 0.054 |
| Pay average | 0.005 | 0.094 | 0.003 | -0.000 | 0.272 | 0.000 | 0.005 | 0.143 | 0.003 | -0.000 | 0.345 | 0.000 |
| Tenure standard deviation | -0.076 | 0.288 | 0.071 | -0.009 | 0.433 | 0.011 | -0.063 | 0.378 | 0.071 | -0.009 | 0.422 | 0.011 |
| Tenure average | 0.100 | 0.092 | 0.059 | 0.011 | 0.250 | 0.009 | 0.083 | 0.169 | 0.060 | 0.011 | 0.242 | 0.009 |
| Age standard deviation | -0.086 | 0.326 | 0.087 | -0.019 | 0.016 | 0.008 | -0.092 | 0.291 | 0.087 | -0.019 | 0.016 | 0.008 |
| Age average | -0.205 | 0.000 | 0.049 | -0.004 | 0.454 | 0.006 | -0.193 | 0.000 | 0.048 | -0.004 | 0.421 | 0.006 |
| *Controls: Firm* | | | | | | | | | | | | |
| Log Firm size | 0.049 | 0.825 | 0.221 | 0.011 | 0.829 | 0.050 | 0.085 | 0.697 | 0.218 | 0.012 | 0.816 | 0.050 |
| Log Firm age | 0.006 | 0.225 | 0.005 | -0.016 | 0.000 | 0.001 | 0.006 | 0.210 | 0.005 | -0.016 | 0.000 | 0.001 |
| Log Physical capital | 0.627 | 0.000 | 0.093 | -0.010 | 0.440 | 0.013 | 0.618 | 0.000 | 0.093 | -0.010 | 0.451 | 0.013 |
| No. of establishmetns | -0.018 | 0.101 | 0.011 | -0.001 | 0.363 | 0.000 | -0.018 | 0.081 | 0.011 | -0.001 | 0.326 | 0.001 |
| Capital region dummy | 0.535 | 0.018 | 0.225 | 0.004 | 0.957 | 0.066 | 0.540 | 0.017 | 0.226 | 0.002 | 0.972 | 0.066 |
| Public dummy | 0.597 | 0.108 | 0.372 | 0.002 | 0.975 | 0.073 | 0.645 | 0.089 | 0.379 | 0.000 | 0.997 | 0.073 |
| Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | |
| Industry fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Firm fixed effects | No | | | Yes | | | No | | | Yes | | |
| Number of observations/firms | 4,151/838 | | | 3,971/660 | | | 4,151/838 | | | 3,971/660 | | |
| Pseudo/Adjusted $R^2$ | 0.708 | | | 0.846 | | | 0.711 | | | 0.812 | | |

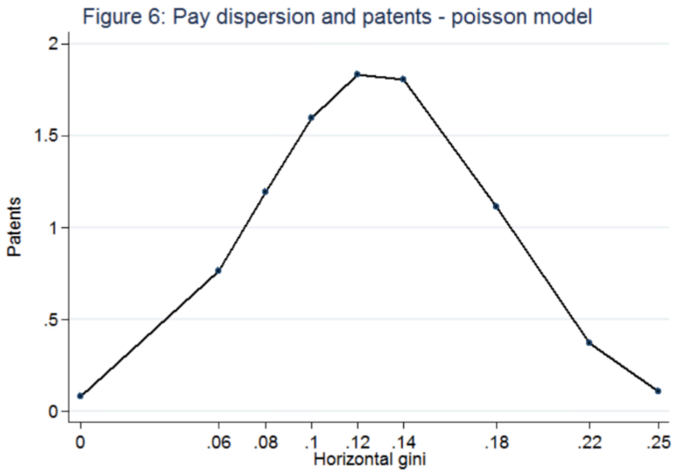
Robust standard errors clustered by firm. Sample restricted to firms with at least 5 R&D employees at relevant firm layers for years 2002-2012. Patents are measured as count of new patent applications (logged in OLS specifications). Model I and model III are poisson estimations and model II and model IV are estimated by ordinary least squares with firm fixed effects. The fixed effects models contain fewer observations as singleton obersvations are dropped.

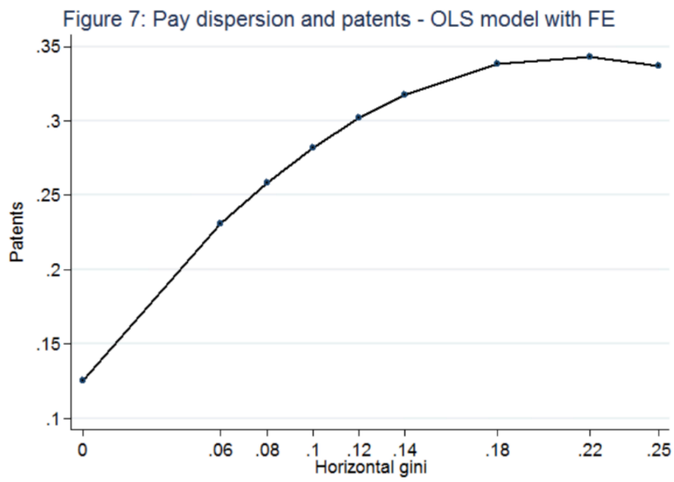
Table 4: **Heterogeneity: Single vs. multi establishment and non-capital vs. capital region**

| | Model V: OLS | | | Model VI: OLS | | | Model VII: OLS | | | Model VIII: OLS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of patents | | | Number of patents | | | Number of patents | | | Number of patents | | |
| *Sample* | Single-establishment firms | | | Multi-establishments firms | | | Non-capital region firms | | | Capital region firms | | |
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Pay dispersion* | | | | | | | | | | | | |
| Horizontal gini | 3.728 | 0.008 | 1.397 | 0.189 | 0.848 | 0.982 | 0.772 | 0.451 | 1.023 | 5.021 | 0.001 | 1.476 |
| Horizontal gini squared | -9.387 | 0.019 | 3.976 | 0.953 | 0.745 | 2.929 | -1.855 | 0.521 | 2.887 | -13.352 | 0.002 | 4.318 |
| Controls | Yes | | | Yes | | | Yes | | | Yes | | |
| Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | |
| Industry fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Firm fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Number of observations/firms | 1,488/283 | | | 2,423/410 | | | 2,036/354 | | | 1,925/309 | | |
| Adjusted $R^2$ | 0.651 | | | 0.870 | | | 0.735 | | | 0.856 | | |

Robust standard errors clustered by firm. Sample restricted to firms with at least 5 R&D employees at relevant firm layers for years 2002-2012. Patents are measured as count of new patent applications (logged). All models are estimated by ordinary least squares with firm fixed effects. In models V and VI, the sample is split by firms with single and multiple R&D establishments. In models VII and VII, the sample is split by firms located outside capital region and firms located in capital region as a proxy for dynamic labor market.

Plotting the marginal effects of the relationship between horizontal pay dispersion and patents, Figure 6 reveals a clear pattern of increasing and decreasing returns when the relationship is modelled without firm fixed effects. The infliction points at which increased pay dispersion become negative for patent performance is at a Gini coefficient of 0.12 with almost have of firms in my sample having dispersion below this point. These results suggest that many firms may benefit from increasing horizontal pay dispersion as opposed to what previous results without the inclusion of a squared term suggest. In the fixed effects estimation, the negative returns to high pay dispersion is less pronounced and with an infliction point of 0.22 implying that 99 percent of the sample could potentially benefit from increasing dispersion.



### 3.4.2 Additional Analyses

In table 4, I split the sample by firms with single R&D establishments and firms with multiple R&D establishments. Results from model V and VI shows that pay dispersion only influence knowledge production in settings where all R&D employees are working at the same physical location. This is an interesting boundary conditions which supports the theoretical mechanism of social comparison, by showing that the proposed motivational effect of social comparison only works for co-workers within close proximity. Model VII and VIII shows that pay dispersion matters only for firms located in the capital region which I take as a proxy for dynamic labour market. The capital region has by far the highest concentration of R&D intensive firms and highly skilled individuals. These results suggest that social comparison plays a role beyond firm boundaries as employees compare themselves with workers of similar functions in other firms in close geographical proximity.

### 3.4.3 Robustness Checks

In this section, I comment on a selection of robustness checks which are displayed in appendix. To alleviate concerns that results are driven by past patent performance, I re-estimate main models controlling for average past three-year patent output. In a separate set of models, I control for R&D intensity which is variable coming from the Community Innovation Survey and is excluded from main models to preserve a large and balanced sample. Table A.2 shows that results are robust to the inclusion of both of these additional controls.

Table A.3 displays the results of re-estimating the main model with different sample cuts with respect to the number of R&D employees at relevant firm layers. Models A-V and A-VI show results of running models with a sample cut of minimum three R&D employees per layer. The signs of main coefficients remains the same but become insignificant in the firm fixed effects model. On the other hand, effect sizes increase when the sample instead is cut at minimum ten

R&D employees at each relevant firm layer as per model A-VII and A-VIII. It is not surprising that pay dispersion matters more in larger team sizes where variation in pay is more likely to occur between members of same function and seniority.

## 3.5 Discussion

In this paper I show, in line with previous studies of pay dispersion and collaborative performance (Bloom, 1999; Yanadori & Cui, 2013), that pay dispersion on the horizontal axis is negatively associated with invention outcomes of firms at least at a first glance. I show, however, that this relationship is non-linear and that increases in horizontal pay dispersion are positively associated with patent output up until a curtain point, after which increases in dispersion becomes negative. Interestingly, most firms would appear to benefit from increases in pay dispersion. These results indicate that the negative effects of increased inequality related to lack of knowledge sharing and feelings of unfairness are outweighed by the positive effects of rewarding differences in employee qualities and efforts.

Horizontal dispersion among R&D employees may not provoke negative feelings as a results of social comparison, because differences in pay can be attributed to measurable quality factors of the individual researcher such as field of specialization, citations, awards, and rank of the institution from which the researcher got her degree. Pay differentials resulting from pay for performance are less likely among R&D employees compared to other business professional as performance in the R&D process is inherently difficult to measure due to a high degree of experimentation (Ederer & Manso, 2013). But if R&D employees are rewarded based on past performance indicators as opposed to current ones, how are they incentivized to increase performance (Alchian & Demsetz, 1972; Vroom, 1964)? Perhaps they are intrinsically motivated by the research itself and pay shall be viewed as a means to incentivize the researcher by rewarding their quality.

Results of the heterogeneity analysis points to important boundary conditions of the influence on pay structure and knowledge production while at the same time finding support of social comparison as a driving mechanic (Fredrickson et al., 2010). Horizontal pay dispersion seem to matter in settings where workers can compare themselves to either co-workers or employees of other firms on close geographical proximity. In sum, this study suggests that increases in pay dispersion may not be detrimental to the creation of knowledge and may even be beneficial in contrast to the idea that knowledge production requires egalitarian structures to promote knowledge sharing (Burns & Stalker, 1994; Yanadori & Cui, 2013).

A key limitation of this study is the lack of ability to draw causal inference. Pay structure may correlate with underlying firm factors such as organizational culture and structure which may affect invention outcomes. An ideal setting to test the effect of pay dispersion on innovation would be a field experiment in which the pay structure of firms is altered to track changes in innovation outputs. A such experiment is infeasible due to costs and ethical issues of altering individuals' pay. Given the observational nature of my data, a source of exogenous variation affecting the pay structure of certain firms or the pay of certain individuals within the firm increase the ability to draw causal inference as such exogenous change in pay would rule out concerns related to the endogenous choice of firm managers to alter pay structure. Though these concerns are to some extent ruled out by the inclusion of a past performance measures and firm fixed effects, richness of the Danish data may enable me and other researchers to get closer at causality in the future.

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# Appendix C Supplementary Material

Table A.1: **Correlation table**

| | | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) | (18) | (19) | (20) | (21) | (22) | (23) | (24) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) | Number of patents | 1.00 | | | | | | | | | | | | | | | | | | | | | | | |
| (2) | Number of forward citations to patents | 0.82 | 1.00 | | | | | | | | | | | | | | | | | | | | | | |
| (3) | Sales from innovation (thousand DKK) | 0.21 | 0.18 | 1.00 | | | | | | | | | | | | | | | | | | | | | |
| (4) | Horizontal gini - R&D workers | 0.04 | 0.02 | 0.06 | 1.00 | | | | | | | | | | | | | | | | | | | | |
| (5) | Vertical gini - R&D workers | 0.11 | 0.09 | 0.05 | 0.18 | 1.00 | | | | | | | | | | | | | | | | | | | |
| (6) | Horizontal gini - Knowledge workers | 0.00 | -0.00 | 0.04 | 0.71 | 0.16 | 1.00 | | | | | | | | | | | | | | | | | | |
| (7) | Vertical gini - Knowledge workers | 0.11 | 0.09 | 0.06 | 0.18 | 0.66 | 0.14 | 1.00 | | | | | | | | | | | | | | | | | |
| (8) | Number of Knowledge workers | 0.27 | 0.28 | 0.28 | 0.20 | 0.01 | 0.14 | 0.05 | 1.00 | | | | | | | | | | | | | | | | |
| (9) | Pay average (Hourly DKK) | 0.03 | 0.03 | 0.04 | 0.34 | 0.03 | 0.40 | 0.04 | 0.09 | 1.00 | | | | | | | | | | | | | | | |
| (10) | Tenure standard deviation | -0.04 | -0.07 | -0.00 | -0.05 | 0.03 | -0.08 | 0.03 | -0.02 | -0.09 | 1.00 | | | | | | | | | | | | | | |
| (11) | Tenure average | -0.05 | -0.06 | -0.02 | -0.10 | 0.04 | -0.15 | 0.05 | -0.08 | -0.05 | 0.86 | 1.00 | | | | | | | | | | | | | |
| (12) | Age standard deviation | -0.05 | -0.05 | -0.01 | 0.04 | -0.00 | -0.04 | 0.01 | 0.02 | -0.06 | 0.26 | 0.17 | 1.00 | | | | | | | | | | | | |
| (13) | Age average | -0.08 | -0.07 | -0.03 | -0.08 | -0.02 | -0.10 | 0.02 | -0.03 | 0.15 | 0.34 | 0.40 | 0.41 | 1.00 | | | | | | | | | | | |
| (14) | Number of managers | 0.05 | 0.04 | 0.16 | 0.09 | -0.04 | 0.08 | -0.06 | 0.29 | -0.01 | -0.03 | -0.07 | 0.04 | -0.02 | 1.00 | | | | | | | | | | |
| (15) | Gini - managers | 0.10 | 0.05 | 0.13 | 0.18 | -0.05 | 0.22 | -0.05 | 0.19 | 0.07 | 0.07 | 0.01 | -0.04 | 0.02 | 0.09 | 1.00 | | | | | | | | | |
| (16) | Firm age | 0.08 | 0.05 | 0.05 | 0.05 | -0.00 | 0.07 | -0.01 | 0.06 | 0.04 | 0.35 | 0.27 | 0.09 | 0.12 | 0.05 | 0.19 | 1.00 | | | | | | | | |
| (17) | Physical capital (thousand DKK) | 0.25 | 0.18 | 0.24 | 0.22 | 0.05 | 0.23 | 0.06 | 0.37 | 0.03 | 0.10 | 0.05 | 0.01 | 0.10 | 0.21 | 0.43 | 0.17 | 1.00 | | | | | | | |
| (18) | R&D spending (thousand DKK) | 0.24 | 0.16 | 0.16 | 0.07 | 0.08 | 0.01 | 0.09 | 0.19 | 0.01 | 0.06 | 0.07 | -0.07 | -0.05 | 0.04 | 0.17 | 0.09 | 0.27 | 1.00 | | | | | | |
| (19) | No. of establishmetns | -0.01 | -0.00 | 0.09 | 0.16 | -0.04 | 0.13 | -0.05 | 0.53 | -0.03 | -0.03 | -0.09 | 0.04 | 0.01 | 0.57 | 0.12 | -0.01 | 0.24 | 0.00 | 1.00 | | | | | |
| (20) | Public dummy | 0.05 | 0.04 | -0.02 | 0.03 | -0.00 | 0.01 | 0.03 | -0.00 | -0.07 | -0.05 | -0.06 | -0.02 | -0.07 | 0.01 | 0.06 | 0.05 | -0.04 | -0.02 | 0.01 | 1.00 | | | | |
| (21) | Capital region dummy | 0.06 | 0.06 | 0.01 | 0.20 | 0.01 | 0.11 | 0.05 | 0.18 | 0.41 | -0.12 | -0.13 | 0.03 | 0.04 | 0.01 | 0.09 | 0.07 | 0.04 | 0.03 | 0.09 | -0.05 | 1.00 | | | |
| (22) | Manufacturing | 0.10 | 0.07 | 0.08 | -0.07 | 0.04 | -0.11 | 0.03 | -0.11 | -0.25 | 0.25 | 0.27 | -0.06 | 0.02 | -0.05 | 0.13 | 0.14 | 0.20 | 0.22 | -0.14 | 0.14 | -0.34 | 1.00 | | |
| (23) | IT & Communications | -0.06 | -0.04 | 0.01 | 0.02 | -0.11 | 0.09 | -0.16 | 0.09 | 0.18 | -0.20 | -0.18 | -0.20 | -0.13 | -0.01 | 0.02 | -0.10 | -0.02 | -0.05 | 0.00 | 0.01 | 0.16 | -0.28 | 1.00 | |
| (24) | Technical services | 0.01 | 0.00 | -0.06 | -0.05 | 0.10 | -0.10 | 0.17 | -0.04 | -0.01 | -0.08 | -0.10 | 0.12 | -0.04 | -0.06 | -0.27 | -0.13 | -0.31 | -0.01 | -0.08 | -0.10 | 0.09 | -0.44 | -0.16 | 1.00 |

All pairwise correlations larger than 0.022 (in absolute terms) are significant at the 5% level

Table A.2: **Control for past knowledge production and R&D expenditures**

| | Model A-I: Poisson | | | Model A-II: OLS | | | Model A-III: Poisson | | | Model A-IV: OLS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of patents | | | Number of patents | | | Number of patents | | | Number of patents | | |
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Pay dispersion* | | | | | | | | | | | | |
| Horizontal gini | 41.599 | 0.000 | 11.816 | 2.191 | 0.012 | 0.866 | 52.827 | 0.005 | 18.663 | 3.006 | 0.007 | 1.107 |
| Horizontal gini squared | -133.072 | 0.001 | 41.296 | -5.276 | 0.034 | 2.479 | -205.830 | 0.002 | 65.203 | -7.704 | 0.017 | 3.217 |
| *Additional controls* | | | | | | | | | | | | |
| Past patents 3-yr. avg. | 1.149 | 0.000 | 0.055 | 0.206 | 0.000 | 0.058 | | | | | | |
| R&D intensity | | | | | | | -0.012 | 0.079 | 0.007 | -0.000 | 0.131 | 0.002 |
| Controls | Yes | | | Yes | | | Yes | | | Yes | | |
| Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | |
| Industry fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Firm fixed effects | No | | | Yes | | | No | | | Yes | | |
| Number of observations/firms | 4,007/806 | | | 3,846/645 | | | 3318/714 | | | 3142/ | | |
| Pseudo/Adjusted $R^2$ | 0.820 | | | 0.816 | | | 0.704 | | | 0.823 | | |

Robust standard errors clustered by firm. Sample restricted to firms with at least 5 R&D employees at relevant firm layers for years 2002-2012. Patents are measured as count of new patent applications (logged in OLS specifications). Model I and model III are poisson estimations and model II and model IV are estimated by ordinary least squares with firm fixed effects. The fixed effects models contain fewer observations as singleton obersvations are dropped.

Table A.3: **Alternative sample cuts: three and ten R&D employees per layer**

| | Model A-V: Poisson | | | Model A-VI: OLS | | | Model A-VII: Poisson | | | Model A-VIII: OLS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of patents | | | Number of patents | | | Number of patents | | | Number of patents | | |
| *Sample* | Three R&D employees per firm layer | | | Three R&D employees per firm layer | | | Ten R&D employees per firm layer | | | Ten R&D employees per firm layer | | |
| | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. | $\beta$ | $p$ | s.e. |
| *Pay dispersion* | | | | | | | | | | | | |
| Horizontal gini | 36.937 | 0.002 | 11.924 | 0.403 | 0.245 | 0.347 | 50.322 | 0.027 | 22.728 | 4.194 | 0.019 | 1.778 |
| Horizontal gini squared | -145.079 | 0.001 | 42.585 | -0.960 | 0.393 | 1.125 | -197.897 | 0.012 | 78.541 | -8.917 | 0.082 | 5.120 |
| Controls | Yes | | | Yes | | | Yes | | | Yes | | |
| Sales growth/investment intensity | Yes | | | Yes | | | Yes | | | Yes | | |
| Industry fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Year fixed effects | Yes | | | Yes | | | Yes | | | Yes | | |
| Firm fixed effects | No | | | Yes | | | No | | | Yes | | |
| Number of observations/firms | 7,941/1,758 | | | 7,474/1.291 | | | 2,408/489 | | | 2,307/388 | | |
| Pseudo/Adjusted $R^2$ | 0.723 | | | 0.783 | | | 0.702 | | | 0.831 | | |

Robust standard errors clustered by firm. Sample restricted to firms with at least 3 R&D employees (models A-V and A-VI) and 10 R&D employees (models A-VII and A-VIII) at relevant firm layers for years 2002-2012. Patents are measured as count of new patent applications (logged in OLS specifications). Model I and model III are poisson estimations and model II and model IV are estimated by ordinary least squares with firm fixed effects. The fixed effects models contain fewer observations as singleton obersvations are dropped.

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